GLOBAL CLIMATE COALITION
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GROWTH IN A GLOBAL ENVIRONMENT

Issues & Options

Potential Global Climate Change

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Preface

The potential for emissions from human activities to cause climate change through enhancement of the Earth's natural greenhouse effect has become an international issue. While certain facts and conclusions in the greenhouse debate are well founded, other information critical for decision-making remains speculative and contentious.

Scientific understanding indicates great uncertainty about the extent of any future climate change, and observations have not yet confirmed evidence of global warming that can be attributed to human activities. However, analyses show that options designed to reduce emissions significantly would be very costly, require major technical innovations, and might require fundamental changes in current human behavior.

Since carbon dioxide emissions from fossil fuels are the primary focus of concern, proposed response options can have profound effects on economic growth, international competitiveness, energy-intensive industries, energy companies, and related environmental issues. This paper describes the scientific, economic and policy issues, and presents recommendations for appropriate actions based on today's limited knowledge.

April 1994

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Executive Summary

Climate Science and Emission Trends

Naturally occurring greenhouse gases, primarily water vapor, carbon dioxide, and ozone, warm the Earth by about 30° C. Without natural greenhouse warming, the Earth would be largely frozen. Water vapor accounts for about two-thirds of the natural greenhouse effect.

Over the past century atmospheric concentrations of greenhouse gases, especially carbon dioxide, methane, nitrous oxides and chlorofluorocarbons, have increased. The international debate concerns the role of human activities in these increases and the risk that continued human-related emissions will lead to global warming and other climate changes.

Direct observations do not confirm any climate change attributable to human action. During the last century, global average temperature is estimated to have risen between 0.3° C and 0.6° C, entirely within the range of natural climate variability. Furthermore, the pattern of global average temperature changes over this period does not correlate with the pattern of man-made greenhouse gas emissions.

Scientific models are currently incapable of providing reliable forecasts of the magnitude, timing or regional impacts of future climate change:

- Key climate processes — especially clouds, ocean circulation, atmospheric chemistry, the role of the biosphere, and solar variability — are not well understood.

- Models amplify direct warming; slight changes in feedback assumptions (for example, water vapor and clouds) could counteract direct warming effects.

- Existing models do not "backcast" history, which calls into question their current usefulness in projecting future climate.

The flows of carbon into and out of the atmosphere are not well understood. Human activities emit about 8 billion metric tons (gigatonnes) of carbon (GtC) per year (6 GtC from fossil fuels and 2 GtC from deforestation), but atmospheric concentrations were growing by about 4 GtC/yr in the late 1980s. The processes that absorb the other 4 GtC/yr are uncertain. To put these figures in perspective, the total flow of carbon into and out of the atmosphere and marine and terrestrial reservoirs due to natural processes is estimated to be 190 GtC per year.

Fossil fuels provide 85% of world energy today. Economic growth will require increased energy use, especially if living standards are to be raised in the

developing world. Due to the abundance of fossil fuels and long lead times to develop and introduce cost-effective alternative fuels, fossil fuel usage (and associated carbon emissions) will continue to grow to meet the energy needs of expanding economies.

Unilateral efforts by industrialized nations will not eliminate concerns about growing carbon dioxide emissions. Based on the Intergovernmental Panel on Climate Change (IPCC) baseline scenario, carbon dioxide emissions from fossil fuels would more than double by 2025, with 80% of the gain coming from non-OECD countries. Even with complete elimination of emissions from OECD nations, world emissions in 2025 would still expand by 60%.

Long-term projections of greenhouse gas emissions and concentrations are very subjective. Extrapolation of recent energy trends for 50 to 100 years results in large increases in carbon dioxide emissions but cannot account for changes in technology, efficiency, energy supplies, and economic activity that will likely slow or possibly reverse the upward trend in emissions.

Economic Costs

The estimation of societal and ecological impacts of potential climate change is uncertain due to the inability of scientific models to provide reliable global, regional or local climate projections.

People have successfully existed in a wide variety of climate zones, and technological innovations have outweighed climate differences. Moreover, climate has little impact upon industrialized economies. For example, less than 5% of the U.S. economy — primarily agriculture — shows large climate sensitivity.

Efforts to stabilize carbon emissions at 1990 levels would be costly and the benefits are unknown:

- According to DRI/McGraw-Hill, U.S. GDP (gross domestic product) would be reduced by 1.4% or approximately $100 billion/yr (in 1992$) by 2000. Implementation would require a carbon tax of around $135/tonne (equal to about $16/barrel of oil or slightly less than 40¢/gallon) and would raise $180 billion/yr in tax revenues. A carbon tax of $800/tonne would be required to achieve a 20% reduction by 2020.

- An assessment by the Energy Modeling Forum of Stanford University estimates that returning to 1990 global emission levels within 50 years would cost almost $4 trillion/yr (4% of world GDP) when fully implemented.

Studies understate costs because they assume least-cost implementation, which is clearly not consistent with U.S. regulatory experience.

Other implications of recent economic studies:

- Actions to reduce greenhouse gas emissions today will impose costs long before benefits (if any) emerge.

- Costs rise at an increasing rate as the target levels of greenhouse gas emissions are decreased.

- Delaying a targeted emissions goal by a decade or so would have a small impact on cumulative emissions but could entail significant cost savings.

Greater resources focused on uncertain future climate issues will divert international attention from more certain and immediate problems of poor countries, and, in the U.S., efforts to improve competitiveness, health care and education reform, and the already full and costly environmental agenda.

Policy Issues

Policy making is complicated by scientific uncertainty, uncertainty about the economic impacts of potential climate change and policies to reduce emissions, the global nature of the issue, and the very long time scales involved.

The highest priority should be to improve scientific understanding of climate. Delaying more severe actions until a credible scientific basis can be established would avoid misguided, nonproductive, and costly steps. The potential for low-cost technological breakthroughs over the next half century could make a nation regret taking premature and expensive actions in the near term even if research later determines that carbon dioxide emissions should be constrained.

Certain actions are worthy of immediate support:

- Accelerate the pace of research into basic climate science and impact assessment.

- Identify and pursue measures that will reduce the threat of climate change, yet also make sense in their own right.

- Establish sustained research and development programs that improve the ability to economically produce and utilize energy with less potential for the accumulation of greenhouse gases.

- Expand efforts to understand and communicate the economic, social, and political consequences of both climate change and proposed policy responses.

Climate Science [1]

Overview

Global climate science involves the study of the entire Earth system including the natural geophysical and geochemical cycles responsible for concentrations of atmospheric gases; the natural climate system of winds, ocean currents, and weather (including precipitation, evaporation and clouds); and the role of biological life, including human activity. The science is complicated by the fact that naturally occurring climate processes are extremely variable both geographically and on all time scales.

Atmospheric gases that absorb and emit infrared (IR) radiation, so-called greenhouse gases (GHGs), affect climate through the global heat balance. Heat that powers climate enters from space as solar radiation and leaves through IR emission back to space. Basic considerations of energy balance show that GHGs warm the Earth by about 30° C. Without the natural greenhouse effect, Earth would be largely frozen. Calculations show that water vapor (H_2O) contributes most to the natural greenhouse effect because of its abundance and because it absorbs at nearly all IR wavelengths. Carbon dioxide (CO_2) and ozone (O_3) contribute by absorbing IR in spectral regions where H_2O absorption is weakest. Water vapor accounts for about two-thirds of the natural greenhouse effect, with CO_2 and all other GHGs, each responsible for about one-half of the remainder.

Concerns about climate change arise because increases in several atmospheric GHGs have been observed — CO_2, methane (CH_4), nitrous oxide (N_2O), and chlorofluorocarbons (CFCs) — and because analyses of trends in concentrations and emissions indicate that increased human activities have contributed to their buildup. Geological evidence, especially from analyses of ice cores covering the last 160,000 years, shows that natural changes in global temperature correlate with changes in atmospheric concentrations of GHGs (for example, CO_2 and CH_4). However, it is not known whether changes in global temperature have led to changes in greenhouse concentrations (for example, by stimulating plant growth or altering ocean chemistry) or vice versa.

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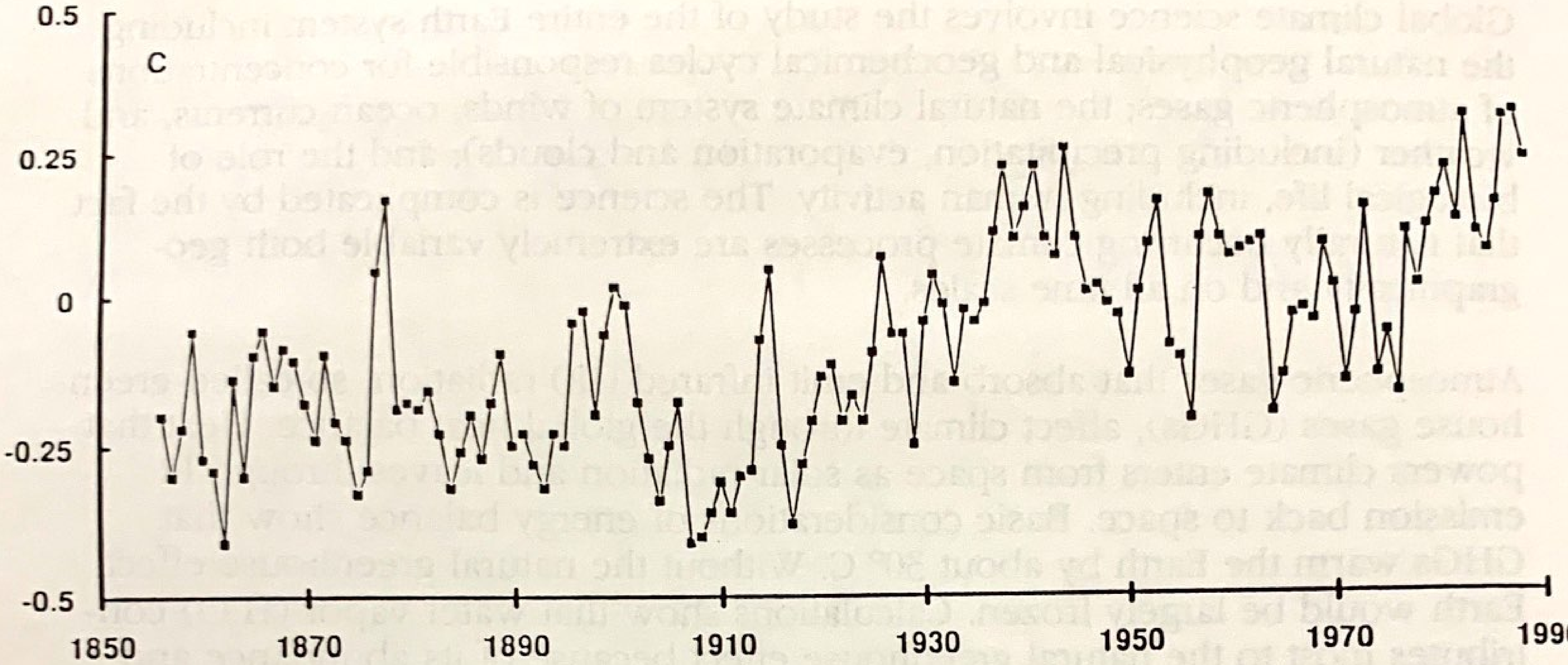
[1] *This discussion of scientific issues is drawn from the reports of the National Academy of Sciences (1991), the comprehensive international assessment reports of the Intergovernmental Panel on Climate Change (1990, 1992), and references cited in those reports, unless otherwise noted.*

Chart 1
Historical Record of Global Average Temperature Change



Change in average temperature relative to a baseline interval 1951-1980.

Source: IPCC 1990.

Historical Record

Since the buildup of anthropogenic GHGs commenced over a century ago, it is reasonable to ask whether accumulated effects to date have produced a recognizable signature of climate change. As seen in Chart 1, the most obvious feature of the global average temperature data over the past 100 years is the high degree of variability, amounting to a few tenths of a degree per year. According to a 1991 study by the National Academy of Sciences (NAS), data show that: "During the last 100 years the average global temperature has increased between 0.3° C and 0.6° C. This temperature rise could be attributable to greenhouse warming or to natural climate variability; with today's limited understanding of the underlying phenomena, neither can be ruled out."

There is no evidence of a warming trend that can be traced to man-made emissions. In fact, the NAS study states that the temperature record could be consistent with either a rising or a falling global temperature trend. Natural variability is such that neither can be ruled out.

The overall pattern of warming is inconsistent with the trend of the buildup of GHGs over time. Despite the rapid increase in anthropogenic GHG emissions that has occurred over the last 50 years, most of the warming since the 1850s occurred prior to 1940 and the trend from 1940 through the late 1970s indicated global cooling. Some point to the global average temperature rise in the 1980s as an indication of global warming. However, this slight rise is well within the range of normal temperature variation and does not confirm a long-term upward trend in global average temperature. Satellite microwave measurements, limited in time only to the past decade, but with global geographical coverage, show virtually no trend in average tropospheric temperature change for the past decade.

Note that global mean temperature is a statistical concept. There are serious issues surrounding the completeness, accuracy, and interpretation of historical data. Available data mostly contain records over land in the northern hemisphere. Some stations have warmed through local urban heating effects, having nothing to do with global change. Data over oceans, especially in the southern hemisphere, are particularly incomplete and records are less reliable for earlier time periods.

Although most analyses of global temperature show evidence of warming, a 1989 study by NOAA scientists (Kirby Hanson, George Maul, and Tom Karl) of U.S. data over the past century concludes that: "There is no statistically significant evidence of an overall increase in annual temperature or change in annual precipitation for the contiguous United States, 1895-1987." And while the United States occupies a small area of the globe, its data are among the most complete and reliable.

Focusing on a single measure of climate — average global temperature — conceals the complexity of measuring temperature and climate change and

provides little guidance concerning potential impacts. For example, as reported in IPCC 1992, average warming over considerable areas of the continental Northern Hemisphere in the last few decades is primarily due to an increase of minimum (nighttime) rather than maximum (daytime) temperatures. The historical record also shows significant differences in decadal temperature patterns between the Northern and Southern Hemispheres over the past 100 years. Furthermore, temperatures in different regions of the Northern Hemisphere, for example, have shown contrasting trends for long periods of time. These observed differences were not predicted by current climate models and remain unexplained.

Modeling Future Climate Change

Investigations of future climate change and its potential impacts on ecosystems and society rely on inherently untestable assumptions about future human behavior and on results from complex, unvalidated computer models that have not been confirmed capable of predicting climate. These investigations describe: (1) future emissions of GHGs, (2) resulting changes in atmospheric concentrations, (3) climate effects from such concentration changes, (4) impacts of climate change on society and ecosystems, and (5) various feedback effects on climate from the impacts on ecosystems and society. To date, although these elements interact in nature, each has been handled in separate models, and each contains numerous areas of serious uncertainty and ignorance.

Claims that serious impacts from human-induced climate change have occurred or will occur simply have not been proven; observations have not confirmed that climate change from increases in GHGs has occurred, and most descriptions of impacts rest either on results from unvalidated and seriously incomplete models or on speculation. To be meaningful, computational models of climate change must include reliable descriptions of numerous climate processes and feedback effects that can either amplify or dampen the direct heating effects of increasing GHGs. With today's limited theoretical understanding, data base, and computational capacity, these feedbacks cannot be described or incorporated reliably into models. Feedbacks include, most importantly, processes associated with water such as clouds, sea ice, evaporation, precipitation, surface hydrology, and atmospheric humidity. Yet, based on IPCC and other assessments, the science is too incomplete to describe these processes reliably — not only in models of future climate change but even in models of current climate.

Most attention has focused on results from massive three-dimensional climate models known as General Circulation Models (GCMs). Based on projected increases in GHGs over the next century, these unvalidated models predict global warming in the range of 1.5° C to 4.5° C with associated climate changes that could have significant impacts on society and ecosystems. Potential impacts might include warming, sea level rise, changes in hydrological cycles, shifts in the distribution of ecological systems and ranges of agricultural crops,

changes in air quality, and changes in climate variability (including the frequency and intensity of storms and drought). Both the rate and magnitude of change may be important for understanding stress on local ecosystems. Impact assessment requires additional assumptions and models, especially to evaluate long-term impacts on ecosystems. Impacts will vary by region; some could even be beneficial. For example, CO_2 increases may stimulate plant growth and reduce their water demand.

The possibility of sea level rise poses a potentially serious threat for low-lying coastal zones. Global sea level has been rising since the end of the last ice age, and is estimated to have risen 10-20 cm over the past 100 years. Among the possible future impacts, the IPCC in 1990 stated that: "A 1 meter [100 cm] rise by 2100 would render some island countries uninhabitable, would displace tens of millions of people, seriously threaten low-lying urban areas, flood productive land, contaminate fresh water supplies and change coastlines."

While these predictions about the impact of a 1 meter sea level rise imply serious consequences, they are based on a hypothetical case and unvalidated model results. Furthermore, estimates of sea level rise have fallen dramatically since the early 1980s when some scientists raised the specter of imminent melting of Antarctic ice sheets leading to a 6 meter sea level rise. Estimates of sea level rise depend on two factors: (1) thermal expansion of oceans and (2) melting of glaciers. In recent studies cited by IPCC, the estimates of sea level rise have decreased, in part because it is now recognized that glacial melting may be offset by an increase in precipitation at high latitudes.

Based on IPCC 1990 emission projections, a recent assessment by Wigley and Raper suggested 66 cm as a "best guess" estimate for global sea level rise through 2100 (in conjunction with a projected temperature rise of 3.3° C). With IPCC 1992 projections, this estimate fell to 48 cm (in conjunction with a projected temperature rise of 2.5° C). The consequences of a 48 cm rise in sea levels would be substantially less than those cited above for a 1 meter rise. The results of Wigley and Raper reinforce the significant reduction in estimates of sea level rise and future temperature increase for the 21st century that occurred in the two years separating the IPCC 1990 and 1992 reports.

While there is no doubt that increased greenhouse gas concentrations trap heat, substantial uncertainty exists regarding the actual amount, timing, and consequences of warming produced by a given change in concentration. Warming triggered directly by changes in GHGs can be amplified or dampened through other climate processes. Today's GCMs indicate that feedbacks amplify direct warming by factors of two to three. However, significant scientific uncertainty exists concerning the proper scientific description of complex feedback processes, especially those associated with the role of water vapor and clouds. For example, slight changes in cloud properties (discussed below) could offset warming associated with CO_2 increases. Other uncertain feedbacks include the role of oceans in heat transfer and the effect of the biosphere and oceans on the buildup of atmospheric CO_2.

Critical Role of Clouds in Models

Climate models are used to identify a relatively small warming effect in the presence of much larger and more uncertain processes. Errors in describing the larger processes can easily give misleading warming projections. Radiative effects of clouds are far larger, more complex and variable, and uncertain than those of CO_2, and they have not been incorporated properly in models of current climate. Climate effects depend on the cloud type, amounts, height distribution and other properties, which models must account for at local scales.

To illustrate the importance of clouds, consider the size of various effects of greenhouse gases and clouds on the global radiation budgets as estimated from models and recent satellite observations. Without additional feedback, models predict that doubling CO_2 concentrations increases atmospheric heating by 4 watts per square meter (W/m^2). Effects of clouds on current climate are estimated to be much larger and actually have a net cooling effect. By reflecting sunlight they are estimated to cool by -44 W/m^2; by trapping IR they heat the atmosphere by 31 W/m^2. Together these result in net global cooling of -13 W/m^2. In models of current climate, cloud effects are often in error by more than ± 20 W/m^2, five times the magnitude from future warming projections. Yet, to reach the more difficult and critical goal of determining how clouds might change as future GHG concentrations change requires filling in significant gaps in scientific knowledge.

Because clouds vary geographically and seasonally, consequences of cloud changes must be evaluated in GCMs, but models do not exist today that can provide reliable guidance on possible changes in the amount, vertical distribution, and microphysical properties of clouds. According to the 1990 IPCC assessment, "there is no *a priori* means of determining the sign of cloud feedback." Most GCM results in the past have shown that changes in clouds amplify warming from increased GHGs. However, these early approximations are known to be seriously incomplete. Slight changes in cloud properties easily offset projected warming associated with CO_2 increases. A study by A. Slingo (1990) finds that radiative forcing associated with doubled CO_2 could be offset by modest increases in the amount of low clouds and modest changes in their microphysical properties.[2]

According to IPCC 1992: "While the treatment of clouds in GCMs is becoming more complex, a clear understanding of the consequences of different cloud parameterizations has not emerged." Moreover, "Observational data on the

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[2] *Slingo (1990) concludes that radiative forcing associated with doubled CO_2 could be offset: "... by modest relative increases of 15%-20% in the amount of low clouds, and 20%-25% increases in liquid water path, and by decreases of 15%-20% in mean drop radius." (The liquid water path refers to the total amount of water in clouds and the drop radius refers to the size of condensed water droplets in clouds.)*

variation of cloud radiative properties in terms of other variables, such as cloud water content and temperatures are relatively scarce."

Uncertainty typically is used by scientists to imply limited precision that can be characterized in probabilistic terms associated with error estimates. In the case of modeling of cloud effects, the problem can be better characterized as ignorance, not statistical uncertainty, and this ignorance prevents us from even assessing how uncertain the model results might be.

Other Limitations of GCMs

GCMs have been used for some time; their limitations are serious and well documented. They include missing or incomplete science, incomplete observational data for calibration and validation, and computational resolution which is too coarse for regional or local climate effects.

• Inadequate scientific understanding of critical climate processes presents the most fundamental difficulty. While some climate processes are well understood or measurable with great reliability, other less understood processes can be modeled with little or no confidence. These include the amount and radiative properties of clouds, ocean circulation, and atmospheric chemistry. Still other processes are so complex, or so poorly understood that they have not yet been incorporated into climate models at all. Perhaps the best example is the uncertain role of the biosphere in the buildup of atmospheric CO_2 concentrations and climate change. While the underlying equations in GCMs are fundamental, they involve many factors that must be treated approximately and others that are ignored altogether.

• Since many critical processes in GCMs cannot be represented by fundamental descriptions, their behavior must be tuned to match observational data. However, there is a lack of reliable data covering long time scales (measured in decades), especially concerning clouds and oceans. Also, there is little agreement about strategies on how to use data to calibrate and validate climate models.

• Computer speed and memory limit resolution to gridblocks whose cells are a few hundred kilometers to a side. Such resolution is too coarse for fundamental descriptions of certain processes (such as clouds and hydrology), and it is the impact on these smaller scale processes — not global average temperature — that is important for understanding the impact on local ecosystems. In other words, it is not currently possible to project either how climate might change at the regional or local level or what the impact on regional or local ecosystems might be. Limited resolution also presents difficulties in interpreting results and making comparisons with observations obtained at local stations.

The predictive limitations of GCMs are summed up in the 1991 report by the National Academy of Sciences: "One major drawback common to all current

GCMs is that they lack adequately validated representations of important factors like cloud cover feedback, ocean circulation, and hydrologic interactions. Therefore it is unreasonable to expect the models to provide precise predictions, decades into the future, of global average temperature. This is especially so given that the expected global temperature rise is smaller than current naturally occurring regional temperature fluctuations on all time scales, daily, seasonal, and decadal."

The report also states: "In essence there are fewer than two dozen GCM simulation runs with five independent models on which to base conclusions. Every one incorporates untested and unvalidated hypotheses. They may be sensitive to changes in ways that current calculations have not yet revealed."

Results from climate models vary considerably from actual climate data and from one another. At the scale required to assess potential impacts, comparisons must be made at regional (i.e., gridblock) scales. Estimates from today's models, even when tuned to match current climate, differ significantly from observations for essential factors such as precipitation.

Projections of future climate differ so much across models that they cannot be used to draw reliable conclusions about potential local impacts. Models do not even agree on the sign (positive or negative) of future regional changes in critical climate variables such as precipitation and soil moisture. The standard disclaimer about the uncertainties in GCMs, as expressed in the 1992 IPCC assessment, states: "... there are many uncertainties in our predictions particularly with regard to the timing, magnitude and regional patterns of climate change."

Although the historical record over the last century shows some warming, it offers little support to confirm greenhouse models because the magnitude and pattern of change differ significantly from model results. In other words, the models do not replicate global temperature history, which calls into serious question their current usefulness in projecting the future. When GCMs are used to "backcast" history, they delineate a pattern of accelerating warming over the past century. By contrast, the historical record (Chart 1) shows intermittent periods of warming (in the 1930s and again in the 1980s) and long periods of little change. The record even shows cooling between the late 1930s through the late 1970s (during which scientists expressed concern about the coming of a new ice age), while the models "backcast" warming.

Attempts to account for the historical variations have led to suggestions that major volcanic eruptions, changes in oceanic upwelling (such as El Niño), and possible fluctuations in sunlight, account for some of the variability. More recent studies suggest that sulfate aerosols from SO_2 emissions may have offset greenhouse climate change, especially in the northern hemisphere.

However, efforts to disentangle these possible effects from the historical pattern are controversial and at best demonstrate plausible, not definitive answers.

Analyses of recently acquired Greenland deep ice cores indicate that natural climate variability may be even larger than had been previously thought. To reiterate, the inability to understand past climate changes casts serious doubt on attempts to model future climate changes.

The best available analyses show that, even if current models were assumed to be correct, confirmation would require at least one and perhaps several decades before any warming signal emerges from natural climate variation. While unanticipated breakthroughs are always possible, improvement in scientific understanding of climate change (via programs now underway to acquire data and develop models to describe cloud effects, for example) will require sustained research over many years.

Recent Critiques of Global Warming Hypotheses

The discussion above draws heavily on conventional assessments of climate change science, which already stress many elements of uncertainty. Over the past decade a number of scientists (including among others, R. Lindzen of MIT, R. Balling of Arizona State University, P. Michaels of the University of Virginia, and R. Jastrow, founder and director (retired) of NASA's Goddard Institute for Space Studies) have advanced evidence supporting the view that the greenhouse effect has been strongly overstated.

These scientists cite records of past climate change that are distinctly at odds with model results. They point out that other factors, such as solar variability, could be dominant agents of past and future global change. They call attention to the point that many impacts of climate change could be positive, in particular those associated with CO_2 fertilization of the biosphere. And they argue that feedback processes, especially those associated with water vapor, could substantially offset potential warming from increased GHGs.

Many of these arguments have received far less attention than they deserve in past assessments of climate change. Among them:

- Lack of evidence in the observational record of climate change despite the significant increase in GHGs that has already occurred.

- Detailed examples of contradictions between observations and model predictions.

- Potential for positive impacts from climate change.

- Role of solar variability in global temperature and climate changes.

Even though these hypotheses and arguments do not eliminate the concern over possible enhancement of the greenhouse effect through man-made emissions, they are extremely relevant for future scientific research and policy analysis.

While CO_2 increases are the primary focus of concern, other gases also contribute. Their relative contribution to IR radiative forcing of climate change depends on their molecular properties and their concentration. Only two years ago it appeared that the relative importance of different human-related gases occurred in the ratio: CO_2: 55%, CH_4: 15%, N_2O: 6%, and CFCs: 24%. These estimated ratios were based on greenhouse gas emissions over the 1980-90 period as reported in the 1990 IPCC report. Energy production, distribution and use were thought to contribute 46% of total human-related GHG emissions over this period; agriculture 9%; forestry about 18%; and CFCs 24%.

Recent efforts, however, have called into question these quantifications. Gases exhibit both direct effects, through absorption of IR, and indirect effects through chemical reactions that influence the concentration of other GHGs. Indirect effects can be substantial and recent studies demonstrate how poorly they are understood. Consequently, scientifically credible results are not available for quantitative comparisons of the importance of different gases.

While this paper will focus primarily on CO_2, efforts to identify and analyze policy options should consider all GHGs:

• CFCs highlight the difficulty of using uncertain science as a guide to policy. CFCs are powerful, entirely man-made GHGs (the direct radiative forcing of CFC-11 and CFC-12 is roughly 15,000 times stronger than CO_2 on a molecule per molecule basis). Because they are thought to contribute to stratospheric ozone depletion, production and use of CFCs are being eliminated. Since 1980, it was firmly believed that elimination of CFCs would provide a significant contribution to reducing the buildup of GHGs. However, new results by Ramaswamy, Schwarzkopf, and Shine (1992) suggest that CFCs' greenhouse effect may be entirely offset through a complex feedback process. Further research is needed to determine the impact of CFC phaseout on potential global warming.

• Like CO_2, the concentration of atmospheric methane (CH_4) depends on numerous complex natural processes as well as human sources. Observations show that CH_4 concentrations have doubled since the late 1800s, from 0.8 to 1.72 parts per million by volume (ppmv). Natural sources include wetlands, termites, and oceans. Human sources include agriculture (especially rice production); animal husbandry; production, distribution and use of fossil fuels, especially natural gas; sewage treatment, landfills and the burning of biomass. Recently, growth rates of atmospheric CH_4 have slowed, and the cause is unknown. Because the atmospheric lifetime of CH_4 is far shorter than that of CO_2, stabilization of concentrations could possibly be achieved with less effort.

• N_2O concentrations have risen 8% since the 1800s and they are a small contributor to radiative forcing. N_2O sources are not well understood, but the

IPCC report suggested that emissions from cultivated soils and biomass burning appear to be the major human sources. Estimates show that contributions from stationary or mobile combustion sources are not large.

• Atmospheric models show that changes in ozone (O_3) concentrations, both in the troposphere and stratosphere, that might occur through indirect effects could be among the most important contributors to changes in the Earth's radiation budget. O_3 changes depend sensitively on combinations of changes in climate and other greenhouse gases. Thus, they are particularly difficult to quantify and to ascribe to specific human sources.

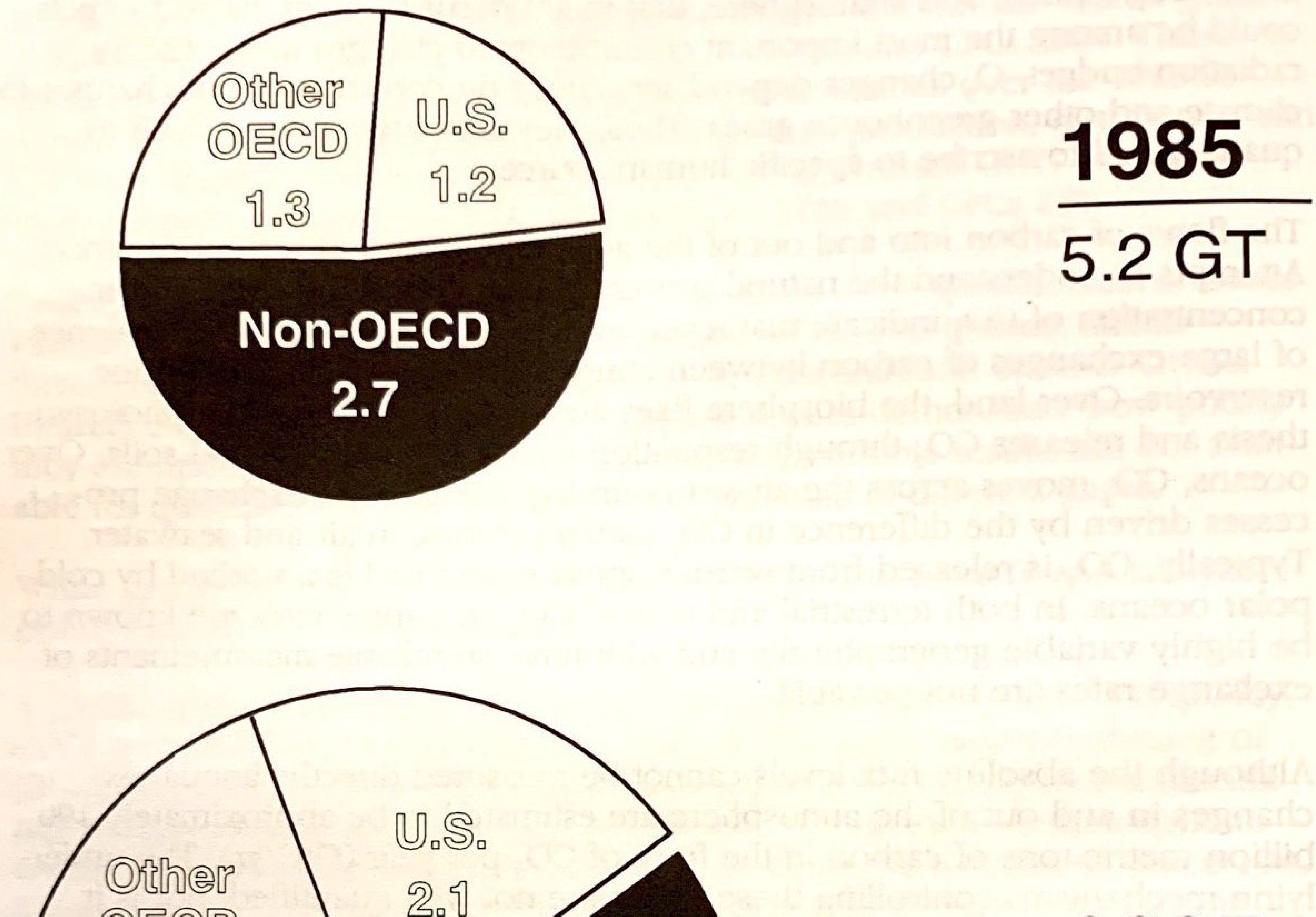
The flows of carbon into and out of the atmosphere are not well understood. Attempts to understand the natural processes that control the atmospheric concentration of CO_2 indicate that levels are maintained by a delicate balance of large exchanges of carbon between atmospheric, terrestrial and marine reservoirs. Over land, the biosphere fixes atmospheric CO_2 through photosynthesis and releases CO_2 through respiration and decay in plants and soils. Over oceans, CO_2 moves across the air-sea boundary through gas exchange processes driven by the difference in CO_2 partial pressure in air and seawater. Typically, CO_2 is released from warm tropical waters and is absorbed by cold polar oceans. In both terrestrial and marine CO_2 exchange, rates are known to be highly variable geographically and with time, so reliable measurements of exchange rates are not possible.

Although the absolute flux levels cannot be measured directly, annual exchanges in and out of the atmosphere are estimated to be approximately 190 billion metric tons of carbon in the form of CO_2 per year (GtC/yr). The underlying mechanisms controlling these fluxes are not well quantified, nor is it known why atmospheric CO_2 levels remained roughly constant from the end of the last ice age (10,000 years ago) until the 19th century. Since the middle of the last century, atmospheric CO_2 levels have risen from about 290 parts per million (ppmv) to 353 ppmv in 1990.

Attempts to reconcile the trend of atmospheric CO_2 growth since the mid-1800s with estimates of past human emissions from fossil fuel use and deforestation show that the buildup generally correlates with growing human emissions. However, observed growth in atmospheric CO_2 concentrations corresponds to only about half the estimated human emission rates. The buildup appears to follow general trends but not on a year-to-year basis.

Human-related activities emitted about 8 GtC/yr in recent years while atmospheric CO_2 was growing by only 4 GtC/yr in the late 1980s. The fate of the other 4 GtC/yr is not well understood nor is it known whether the ratio of the buildup in the atmosphere to the emission rate will increase or decrease in the future. Natural processes may also play some role in the recent increases. Moreover, it is possible that climate change could alter the natural flux balance with significant, but as yet unforeseen, consequences. Press reports indicate

Chart 2
Regional Fossil Fuel CO_2 Emissions



Source: Reference Scenario, IPCC (1990).

that growth in atmospheric CO_2 has slowed dramatically, and nearly ceased altogether in the past year. While changes in the rate of growth have been closely observed previously, the apparent slowdown is without precedent or explanation, indicating how little is known about factors that control atmospheric CO_2 concentration and our ability to predict its future variation.

It is important to distinguish between trends in GHG emissions and trends in atmospheric concentrations. Emissions govern the rate of concentration change. Over the past 150 years, observations show that CO_2 concentrations tend to grow at approximately 50% of emissions. CO_2 does not decompose in the atmosphere. Rather it cycles between land, marine and atmospheric reservoirs, through a variety of processes, such as photosynthesis, that are difficult to characterize in geochemical models. However, CO_2 additions appear to remain in the atmosphere for a long time — IPCC gives estimates in the range of 50 to 200 years. If emissions were stabilized at today's levels of 8 GtC/yr, and if the past relationship between emissions and concentrations continued, concentrations could be expected to grow 4 GtC/yr. Ultimately some new, higher equilibrium level of atmospheric CO_2 concentrations would be established, but the time involved is many decades, and the ultimate concentration level cannot be forecast with any reliability.

In its 1990 assessment, the IPCC sought to establish how much CO_2 emissions would have to be reduced for immediate stabilization of atmospheric CO_2 concentrations at today's levels. The IPCC estimates are obtained from an incomplete model of the uncertain processes that control the carbon cycle. In addition, the IPCC imposed the simplifying assumption of immediate emission reductions with no possible effects of climate change itself on the carbon cycle. IPCC model results indicate that CO_2 emissions would need to be reduced by more than 60% immediately, that is, to less than 3 GtC/yr, to stabilize concentrations at today's levels. There is no simple explanation for the IPCC finding that more than a 60% reduction in emissions would be needed to stabilize CO_2 concentrations; it is based on estimates derived from several models that incorporate different approaches and simplifying assumptions.

Man-made CO_2 emissions occur principally from energy use and partly from deforestation. In 1990, emissions from energy use amounted to 6 ± 0.5 GtC/yr. Data on CO_2 emissions from deforestation are not available on a yearly basis. Averaged over the decade of the 1980s, they amount to 1.6 ± 1 GtC/yr, primarily from developing nations. On a relative scale, where CO_2 emissions per BTU from oil are taken as one, natural gas is 0.7 and coal is the most carbon-intensive at 1.25. Based on recent energy use patterns, global CO_2 emissions from fossil fuel usage occur in the ratio: oil (41%); coal (41%); gas (18%). Sectoral shares of emissions from OECD nations are: transportation (33%), industrial (35%), and residential (32%). Regional differences are apparent, however. For example, as a share of total emissions, developed countries produce far more CO_2 from transportation than developing nations.

As Chart 2 taken from the IPCC Reference Scenario (1990) shows, OECD nations accounted for approximately half (2.5 Gt) of the 5.2 Gt global CO_2 emissions from fossil fuel use in 1985, but their share has been falling and should continue to do so. Although OECD emissions are expected to rise to 4.2 Gt/yr in 2025, their share of global emissions is expected to fall to 34%. For comparison, the global share of United States CO_2 emissions is expected to fall from 24% in 1985 to 17% in 2025 under this IPCC scenario, despite a projected increase from 1.2 Gt in 1985 to 2.1 Gt in 2025. The United States share of OECD emissions is projected to remain close to its current share.

Global CO_2 emissions from fossil fuels are expected to more than double to 12.4 Gt in 2025. Of the 7.2 Gt worldwide increase projected from 1985 to 2025, 5.6 Gt (nearly 80%) are expected to be emitted from developing and former communist nations. Many developing countries are in the high-growth phase of development when energy use commonly grows faster than GDP. In addition, developing nations are expected to account for over 90% of the 1.8 billion increase in global population 1990-2010, according to UN projections. In mature industrialized economies, economic growth rates are likely to be lower and growth in energy use to continue to lag behind GDP growth.

Unilateral efforts to reduce emissions by developed nations will therefore not be enough to reverse the growth trend of emissions. In the 2025 scenario depicted in Chart 2, unilateral action to stabilize emissions in the United States and other OECD nations at 1985 levels would still lead to a doubling of global CO_2 emissions by 2025. Even if the OECD nations eliminated all of their emissions, world emissions in 2025 would still expand by 60% compared to 1985 levels.

Long-Term Scenarios of Future Greenhouse Gas Emissions

Because it is cumulative emissions over very long periods of time that affect atmospheric concentrations, IPCC and others develop scenarios of future greenhouse emissions to 2100 to assess the magnitude of the potential problem and the level of effort that might be required to limit emissions.

Recognizing the difficulty of projecting energy use 100 years into the future, the IPCC developed a number of very long-term scenarios incorporating a variety of assumptions. IPCC scenarios estimate CO_2 emissions in the range 5 to 36 GtC/yr in the year 2100. In all cases of increasing emissions, growth in developing countries dominates projected increases.

Scenarios with the highest emissions assume that society enters an era of coal-derived synfuels, as conventional fossil fuel supplies dwindle. Low-side projections assume the development of cost-competitive, low-carbon or non-carbon-based fuels and technologies. At the higher end of emissions, atmospheric CO_2 concentrations could approach 800 ppmv by 2100.

A baseline emissions path that rises for a period of time but then declines over the 21st century would clearly require much less severe policy responses (if climate change is found to be a significant problem) than a path that rises to 36 GtC in 2100. The more optimistic one is about technological progress over the long term, the less need there would be to require costly emission reductions in the near term.

The energy path over the next century will depend on how the relationship evolves among population, economic growth, energy use and technological progress. The past can reveal trends, but history also reveals abrupt twists and turns unforeseen by previous generations.

The availability and prices of fossil fuels are key determinants of energy intensity in an economy. Despite record use of petroleum worldwide in the 1980s, proven world oil reserves are at an all-time high and would supply world needs for 40 years at 1990 consumption levels. There are 50 years of natural gas reserves worldwide and 280 years of coal resources. In addition to 40 to 50 years of oil and gas supplies, experience has shown that ongoing exploration and development activities generate additional knowledge of the resource base and promote the evolution of improved extraction technologies. These lead to additional discoveries and techniques for developing reserves not previously considered economically feasible. As a consequence, the inventory of proved reserves has grown with time and one should not expect a major reversal of that trend any time soon. Nor should one expect fossil fuel prices to rise at a rate in the near term that would soon reverse the trend in GHG emissions.

Technological progress will continue to improve energy efficiency. History leads one to expect that efficiency gains will slow the worldwide growth of fossil fuel consumption, but an outright decline should not be expected over the next several decades. Lower rates of growth in energy use due to efficiency improvements, other things being equal, should delay the timing of large energy price increases related to fossil fuel depletion.

Why does the path of energy prices matter for greenhouse policy making? Emissions can be reduced through a variety of means. One way would be for the price of fossil fuels to rise significantly such that non-carbon alternative fuels become competitive without major reductions in their costs. On the other hand, innovation could significantly lower the costs of alternative fuels such that they displace fossil fuels without major price increases. Lastly, policy-makers could mandate the use of alternative fuels prior to the time that they are competitive with fossil fuels. The cost of alternative fuel mandates is related to how close the costs of alternatives are to the cost of fossil fuels. In the absence of major breakthroughs in lowering the costs of alternative fuels, it would be very expensive to significantly back out fossil fuels over the next several decades because of their relative abundance.

When projecting 50 years or more into the future, technological advances in the production and use of energy should be anticipated. But it is highly presumptuous to speculate about the cost, performance and penetration rates of energy technologies not yet invented. When will technological breakthroughs dramatically lower the cost of solar photovoltaics or nuclear fusion? Will the world have to turn to oil shale, tar sands and synthetics from coal — each more carbon-intensive than current sources of liquid and gaseous fuels — as conventional sources of fossil fuels dwindle? Will advances in superconductivity or cold fusion or something unimagined today drastically alter the energy landscape? Will technologies advance to remove and sequester carbon from energy conversion processes, in effect making fossil fuels significantly less carbon-intensive in some uses? Forecasts of climate change are dependent on just such speculation about long-term technological change and its impact on long-term emissions, and those forecasts are driving policy debates about how much emission reductions are needed today.

Suppose it were 1893 instead of 1993 and we were asked to forecast energy use a century into the future. At that time, animal power was a major energy source worldwide. Diesel engines, airplanes, plastics, LNG, nuclear power, satellites and microchips were unknown. Historical relationships between fossil fuel use and economic growth based on data between 1843 and 1893 would have been largely useless in forecasting energy use for the next 100 years. Over the past century, our capabilities to extrapolate from trends have improved, but our crystal balls still cannot forecast the unexpected, including scientific insights and technological breakthroughs.

Economic Issues

To develop appropriate policies, decisionmakers need reliable estimates of (1) the costs and benefits of any future climate changes with and without actions to constrain GHG emissions and (2) the costs and benefits of constraining emissions. Efforts to estimate the costs and benefits of potential global climate change as well as attempts to estimate the benefits of constraining GHG emissions (i.e., how climate changes would be lessened by various levels of emission constraints) founder on the inability of scientific models to provide reliable climate projections. We do know that observable climate-related benefits, if any, of emission constraints today would not show up for a long period of time (decades). On the other hand, the cost of introducing constraints today would be substantial and immediate.

Economic Impact of Climate Change

Numerous studies have tried to quantify the cost of climate change with respect to agriculture, forestry, sea level rise, space heating and cooling, health, changes in storm severity, water supply, local and regional pollution, and infrastructure. However, climate models are incapable of projecting changes in the timing and magnitude of regional and local climate variables such as seasonal and daily temperatures, rainfall patterns, transpiration rates, soil moisture, dates of first frost, and winds that are critical for understanding impacts on ecosystems, agriculture and other climate-sensitive economic sectors. Because GCMs are incapable of providing reliable regional forecasts, quantifications of the regional economic impacts of climate change are themselves highly speculative and unreliable.

With respect to ecosystems, impacts would depend on the magnitude and also the rate of climate change if such changes occur faster than the pace of natural adaptation. However, prediction of impacts on ecosystems is hampered not only by the inability of climate models to produce reliable forecasts of change (or even their direction) at the appropriate regional level, but also by the limited scientific understanding of the response of natural ecosystems to long-term climate change. In any case, assigning economic values to changes in ecosystems is highly speculative regardless of the state of scientific knowledge concerning climate change.

One frequently quoted economic analysis is the 1991 study by William Nordhaus, an economics professor at Yale University. He projected that the future cost to the United States of adjusting to climate changes from a doubling of CO_2 concentration would range between 0.3% and 1% of GDP per year. To reiterate, all of the estimates, including Nordhaus', of the various costs of climate change (except those for sea level rises) are dependent on unreliable forecasts of the magnitude and timing of changes in regional climate variables.

Sea levels, however, would be affected primarily on a global scale and regional climate forecasts would not be as critical to calculate sea level rises. Of course, the inability of GCMs to forecast the magnitude and timing of climate changes on a global scale also limits the ability to estimate the cost of sea level rise. Several studies have made an assumption about sea level rises (1 meter rise by 2100 is most common) and then calculated the cost of building protective levees and the value of lost wetlands and flooded drylands.

According to Morgenstern (1990), EPA estimates that the annual United States cost of a 1 meter sea level rise would be around $10 billion per year (based on $370 billion in future capital, maintenance and operating costs discounted with a 3 percent rate). Cline (1992) points out that Morgenstern's estimate fails to take into account the long phase-in of capital outlays for protective levees and he estimates the cost at about $7 billion per year (less than 0.2% of today's GDP).

In a 1991 study for the OECD, Rijsberman estimates that a 1 meter rise by 2100 would cost OECD countries about $800 billion (undiscounted) over the next century in terms of lost wetlands and beaches, protective structures and additional infrastructure — around 0.1% of aggregate OECD GDP annually. Although the United States and OECD estimates are not directly comparable because of different assumptions about the timing of a 1 meter rise and the use of discounting, the important point is that the future cost of a 1 meter sea level rise would be a small fraction of 1 percent of annual GDP in OECD nations.

Certain island nations and countries with significant low-lying coastal areas would suffer much larger economic harm, measured as a share of GDP, from a 1 meter rise in ocean levels. For example, the IPCC estimates that the cost of erecting protective structures in the event of a 1 meter sea level rise would cost the Maldives about one-third of its GDP annually. Over 10% of Egypt's and Bangladesh's arable land would be inundated. EPA estimates that 70 million people would be displaced in China from a 1 meter sea level rise in the absence of protective structures. According to studies cited by Cline, Europe and the former Soviet Union would be less affected than other areas.

The variance in the estimates of the cost of a 1 meter sea level rise result because the timing and magnitude of sea level rises cannot be quantified reliably using today's GCMs. Thus, discounted cost estimates such as Morgenstern's and Cline's, which depend on the timing of the rise, are also unreliable. Moreover, as discussed above, the current thinking is that the sea level rise would be substantially less than 1 meter for a doubling of CO_2 and, therefore, would result in significantly lower economic costs.

The climate sensitivity of economies can also be discussed in qualitative terms. The discussion that follows builds on the fact that humans and their institutions, especially market-based economic systems, have done well in adjusting

to a wide variety of factors, including climate, that affect tradeable and substitutable resources.

Societies have adapted to a range of temperature and climate that far surpass the potential range of temperature differences outlined in IPCC reports. People successfully exist in a wide variety of climate zones ranging from the frigid Arctic plains to the deserts of the Middle East to the tropical rain forests. Americans, for example, have been migrating to the warmer climes of the Sunbelt for the past half century. Technological innovations (air conditioners, refrigeration) have outweighed climate differences. Massive shifts in agricultural production have also taken place. California had little crop production in 1900; by 1985 it had twice as much as second place Iowa.

Climate has little impact upon industrialized economies. For example, Nordhaus (1991) estimates that over 85% of the United States economy is negligibly impacted by climate. Only agriculture and forestry — comprising 3% of U.S. GDP — have a high potential of being affected by climate change. About 10% of GDP — construction, recreation, etc. — has a moderate potential of being affected by climate change. But even in the moderate and high potential sectors, it is not certain that the economic impact of climate change would be negative. Warmer winters could reduce construction downtime due to frigid weather. Certain crops may be harmed but others may be favored by climate changes.

That modern economies are largely insensitive to climate is not surprising. Education, training, investment, and economic policies, as well as political and legal systems, are much more important for most investments than climate. Climate has little to do with a company's decision whether to make semiconductors in San Francisco vs. Helsinki vs. New Delhi. People and businesses adjust to much wider variations in temperature and weather over the course of a day or season than is likely to occur with climate change. In most situations, equipment and structures are replaced at a faster rate than any projected pace of climate change; industry, in general, should be able to adjust.

Developing nations might be more susceptible to climate changes. The labor force has less education and lower skill levels with which to adapt to future climate changes. Their economies are more dependent on agriculture and their lower income levels may make it more difficult to adapt quickly. On the other hand, controlling GHG emissions may also be more costly if funds are diverted to deal with speculative problems that may arise decades in the future and away from investments necessary to reduce the immediate miseries resulting from pervasive poverty in these nations.

With respect to the potential impact of climate changes decades into the future, Thomas Schelling, an economist at the University of Maryland, notes: "If life, culture, technology and economics change as much in the next 90 years as

they have changed since the turn of the century, we may be no better able to imagine, for Europeans or for Asians, what the significance of alternative climates would be."

The point is not that adaptation to climate change 50 or more years from now will be costless or frictionless, but that the impacts on people are likely to be overshadowed by political, economic and technological changes unrelated to climate changes.

Estimates of the Cost of GHG Emission Controls

Study after study predicts that government action to restrain the growth in GHG emissions will indeed be costly. Studies cited below estimate that the cost of maintaining a target level of GHG emissions will increase over time in the absence of major technological breakthroughs. Attempts to progressively lower emission targets will cause costs to rise at an increasing rate. But model results [for example, Manne and Richels (1991) discussed below] indicate that costs can be significantly reduced if emission reductions are delayed, thereby allowing economies longer to adjust to emission restrictions and to allow the introduction of new technologies. Costs would be increased if policies force the premature replacement of expensive facilities, such as power plants, that were designed on the basis of long useful lifetimes.

Different Kinds of Models for Different Time Frames

Because the time frame of analysis stretches from the remainder of this decade to the end of the 21st century and even beyond, different types of economic models have been designed depending upon the time frame of reference. (Note: when considering climate issues, the near-term stretches to 20 years or so and the long term is a century or more.) Imposition of a carbon tax, for example, will disrupt the economy and lead to unemployment, serious sectoral and regional dislocations, and reduced economic growth. Efforts to make major changes in fundamental human activities — power generation, transportation, manufacturing, housing, heating and cooling, and agriculture — would most assuredly have significant macroeconomic repercussions. After the passage of enough time, economies eventually would adjust to the changed policy and return to full employment, but at lower levels of income and rates of GDP growth as investment is diverted toward reducing emissions.

Certain models, such as DRI/McGraw-Hill's, are expressly designed to capture the macroeconomic costs incurred in the transition to a new full-employment growth path. But because of the data requirements and model complexity, these models function best in analyzing short-term effects occurring within the next several years up through the next decade or so. Numerous other energy/economic models [for example, many of those in the Energy Modeling Forum (EMF) study detailed below] have been designed to focus on the impact of

policies over very long time periods. These models do not capture macroeconomic disruptions from policy change; they assume economies adjust quickly and focus on the negative effect of emission constraints on the full-employment economic growth path. These long-term-oriented models often have more detailed sectoral descriptions of energy supply and demand, including a wide range of technological options, than do the macroeconomic models.

Over very long time periods, transition costs are likely to be of less importance than the dampening effect of GHG emission policies on long-term economic growth rates. Nonetheless, people, businesses and governments have to live through the shorter-term dislocations of job losses, bankruptcy, housing devaluations, etc. For some regions and sectors, the dislocations associated with emission constraints would entail large costs; and recovery, if at all, could take years. Families, businesses and politicians are sure to be less willing to accept potentially severe and costly dislocations in the near term in those cases (such as climate change) in which the benefits of a policy are remote in time and especially uncertain.

Key Assumption: Policy Implemented to Minimize Aggregate Costs

Before turning to the model results, it is important to understand a key assumption in economic models about how policy is implemented. Economic costs are generally estimated under the assumption that policies designed to meet a specific carbon emission limit are imposed in such a way as to minimize the aggregate impact on economic growth. The models generally employ carbon taxes and project the cost-minimizing carbon tax path needed to achieve a given target. The carbon tax approach serves two purposes in modeling efforts: (1) carbon taxes explicitly raise prices of various fuels based on the carbon content of a fuel and energy prices are the main drivers in these energy/economic models; (2) carbon taxes reveal the minimum marginal cost required to achieve a given emissions target. Compared to modeling the impact of carbon taxes, it would be much more difficult to model efficiency standards for hundreds of different technologies.

The assumption of least-cost implementation is certainly not consistent with decades of experience with energy, environmental and tax policymaking in the United States. In practice an emissions reduction policy would likely be considerably more expensive than the estimates found in the economic studies cited below. Tax codes generally include special exemptions and penalties that move policy away from cost-minimization.

The use of command and control regulations, instead of a carbon tax, would not have explicit costs; but they would generate implicit costs that must be paid and that would retard economic performance in the same manner as a carbon tax. Moreover, because of a lack of information necessary for government planners to identify least-cost actions and because of political influence

Table 1
Real GNP/GDP and Unemployment Impacts of Constraining CO_2 Emissions in OECD Countries[1]

Country	**Real GNP/GDP[2] 1995-2020**	**Unemployment Rate[3] 1995-2020**
United States	-3.1	0.4
Canada	-2.4	0.9
Japan	-1.5	0.2
Australia	-3.5	0.2
Europe	-2.3	0.3
Germany	-2.1	0.1
France	-1.7	0.1
Italy	-2.7	0.6
United Kingdom	-2.5	0.6
Sweden	-1.0	0.2
Spain	-3.3	0.6
Netherlands	-1.9	0.1
Greece	-3.5	0.8
Total	***-2.4***	***0.3***

[1] Assumes each country stabilizes carbon dioxide emissions at 1988 levels by 2000, and then reduces emissions to 10% less than 1988 levels by 2010 and 20% below 1988 levels by 2020.

[2] Average annual percent difference from the base case GNP/GDP level.

[3] Average annual percentage point difference from the Base Case unemployment rate.

Source: DRI/McGraw-Hill, *Economic Effects of Using Carbon Taxes to Reduce Carbon Dioxide Emissions in Major OECD Countries,* January 1992, page 8.

that regularly overrides economics, the cost of command and control regulations would be much higher than the estimates found in the studies cited below.

Economic Model Results

Two things stand out in the following review of model results: (1) the wide range of cost estimates and policy efforts deemed necessary to meet similar targets and (2) the uncertainty associated with modeling over a 50 to 100 year period. The first point is discussed below. The second point is illustrated by the 1991-92 assessment of 14 energy/economic models undertaken by the Energy Modeling Forum (EMF) of Stanford University (which includes models developed by EPA, DOE, OECD, IEA, EPRI, and leading academic experts and consultants such as Jorgensen and Wilcoxen, Edmonds and Reilly, and Manne and Richels). Key economic variables were standardized in order to develop baseline GHG emission forecasts on a consistent basis in all of the models. Despite this standardization the models' estimates of year 2100 baseline carbon emissions in the United States ranged between a 20% to 200% increase over 1990 levels.

DRI Model Results

In a January 1992 study of the impact of CO_2 restraints in OECD countries for the United States Department of Commerce, DRI/McGraw-Hill utilized its macro-economic/energy models to consider transition effects. DRI estimates that stabilizing year 2000 emissions at 1988[3] levels would reduce the United States GDP in 2000 by 1.4% or around $100 billion (1992$). This income loss would translate into over $900 per household in 2000. Cumulative GDP losses through 2000 would total around $500 billion.

The DRI study also estimated the cost of reducing emissions 10% below 1988 levels by 2010 and 20% by 2020. The annual loss in U.S. GDP would average more than 3% of GDP over the 1995-2020 period. Cumulative GDP losses would amount to $6 trillion over this period.

United States industrial output would be even more negatively affected than GDP, signifying an accelerated shift in the composition of the economy toward services. Given the slower GDP growth and the shift away from the high-wage industrial sector, it is not surprising that wages would be adversely affected. Real wages would be 2.5% lower than the "base case" in 2000 and 12% lower in 2020. Furthermore, the level of employment would be 600,000 lower on average over the entire period and average annual consumer inflation would be almost 1% higher.

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[3] *For the U.S., 1988 and 1990 CO_2 emissions are virtually identical. Thus, the DRI results would not change if the objective had been stated in terms of the 1990 level of emissions.*

Table 2
Carbon Tax[1]
(1992 dollars per tonne carbon)

Country	1995	2000	2010	2020
United States	35	134	429	804
Canada	37	160	482	752
Japan	175	448	1217	2710
Australia	81	225	874	1639
Germany	123	327	731	959
France	155	386	689	1644
Italy	90	221	961	1756
United Kingdom	30	81	546	1095
Sweden	23	65	511	546
Spain	203	493	1464	2251
Netherlands	74	188	790	1194
Greece	108	282	1042	1765

1 Assumes each country stabilizes carbon dioxide emissions at 1988 levels by 2000, and then reduces emissions to 10% less than 1988 levels by 2010 and 20% below 1988 levels by 2020.

Note: GDP price deflater used to adjust 1989$ reported by DRI to 1992$.

Source: DRI/McGraw-Hill, *Economic Effects of Using Carbon Taxes to Reduce Carbon Dioxide Emissions in Major OECD Countries,* January 1992, page 8.

In the base case, aggregate carbon emissions from United States energy use were projected by DRI to rise 6% between 1988 and 2000 and 25% between 1988 and 2020. Relative to the base case, emissions would have to be cut 6% in 2000 to achieve 1988 emission levels and they would have to be reduced by 37% in 2020 to reach the goal of a 20% decline below the 1988 level of emissions.

DRI estimates that a carbon tax of $134/tonne (1992$) would be necessary to hold 2000 emissions in the United States at 1988 levels and that the tax would have to rise to $804/tonne to reduce 2020 emissions by 20% below 1988 levels. A $134/tonne carbon tax would raise oil prices by about $16/barrel or slightly less than 40 cents a gallon; natural gas prices by $2.00/mcf and coal prices by $72/short ton. Carbon tax revenues would amount to $180 billion/year at the 1988 level of carbon emissions. The study assumes that these revenues are rebated via the personal income tax.

As a point of reference, the BTU tax proposed in early 1993 would have raised around $30 billion/year, or less than 5% of the revenue to be raised by the $804/tonne carbon tax needed to reduce emissions by 20% below 1988 levels. The BTU tax was replaced by a 4.3 cents/gallon rise in the motor fuels tax in the final budget agreement. If, instead of a carbon tax of $134/tonne on all fossil fuels, stabilization of carbon emissions at 1988 levels was to be achieved solely with an increase in the motor fuels tax, then the motor fuels tax would have to be raised by more than $1.40/gallon.

Because natural gas has the least carbon per unit of energy and coal the most, a $134/tonne carbon tax would raise natural gas prices somewhat less than $2.00/million BTU; oil prices by around $2.70/million BTU; and coal prices by about $3.50/million BTU. Yet, at that carbon tax rate, United States oil consumption, relative to the base case, would be reduced the least and coal usage the most. Oil consumption would fall by about 5% relative to the DRI base case in 2000; natural gas use would fall by about 7%; and coal consumption would be cut by 10%. Natural gas is projected to capture a larger percentage of the base case energy growth through 2000 than its current share of energy and, thus, almost complete elimination of fossil fuel energy growth affects natural gas usage to a larger degree than oil consumption despite the higher tax on oil per unit of energy.

A tax of $804/tonne would cut both oil and natural gas use in the United States by about 23% relative to the base case in 2020; coal demand would be cut by 54%. Thus, instead of growing 0.7%/year over the 1988-2020 period, natural gas use would actually decline 0.1%/year over this period given the projected schedule of carbon taxes. In the base case, oil usage would have grown 0.5%/year from 1988-2020 but would decrease by 0.3%/year given the projected carbon taxes. Coal growth would fall 1.4%/year compared to 1%/year growth in the base case.

DRI results show that the economic impact of stabilization by 2000, a 10% cut by 2010 and a 20% cut by 2020 would be much more severe in the United States than in other key OECD nations (see Table 1). The 3% annual percentage loss of GDP in the United States for 1995-2020 would be twice as great as the annual percentage GDP loss in Japan and 50% more than in Germany. United States losses as a share of GDP would also be 25% higher than the average OECD nation. Yet, as seen in Table 2, other OECD nations, in general, would have to enact even higher carbon tax rates than in the United States to achieve the DRI emission constraints.

Sweden, Japan and France lose less than 2.0% of their GDP in the face of stiff carbon taxes because they have the greatest opportunity for fuel substitution. Sweden is expected to reduce exports of hydroelectric power in order to meet electric needs at home and to increase reliance on natural gas. Imposition of carbon taxes is projected to spur Japan to increase LNG imports substantially and to increase the role of nuclear power. France is expected to reduce exports of nuclear-based electricity to meet power needs at home. In comparison, natural gas already plays a more important role in the energy mix in the United States than most OECD countries so that future opportunities for switching to natural gas are fewer. Political opposition to new nuclear power facilities also is expected to continue in the United States. The reason for the smaller economic impact on Germany results not because of relatively more fuel substitution options than in the United States but because the structure of the German economy is projected to be more responsive to rising carbon taxes.

EMF Study Results

Although each model in the EMF assessment, including those developed by EPA and DOE, builds in the introduction of advanced technologies and continued increases in energy efficiencies in each baseline, all still project that costly government intervention would be required to limit carbon emissions to 1990 levels or below. There are no energy efficiency or technological "free lunches" that would make stabilization of emissions at 1990 levels costless. In the EMF study, stabilization of United States carbon emissions in 2000 resulted in GDP losses of 0.1% to 0.5% per year; a target requiring 20% reduction below 1990 levels in 2010 would cost between 0.9% to 1.7% of GDP. To put these numbers into perspective, a 0.3% GDP reduction in 2000 would be $20 billion/year (in 1992$) and a GDP reduction of 1% in 2010 would amount to around $75 billion/year. Cumulative costs would, of course, be much higher. EMF models found that a 20% reduction below 1990 levels in 2010 would require carbon taxes ranging between $50/tonne to $350/ton (1992$).

The estimates of the EMF models differ among themselves and with the DRI cost estimates because of, among other things, differing assumptions about the degree of substitutability among fuels, the rate of technological innovation, and the ability to substitute capital and labor for energy. In contrast to the DRI model, most of the EMF models are not designed to consider short-term transi-

tion costs and their estimates of costs of meeting a year 2000 or 2010 target are understated.

The EMF study also projected that a program to stabilize world emissions at 1990 levels, phased in over 50 years, would lower the level of world GDP by 4% when fully phased in. Four percent of world GDP today is around $1 trillion (1992$) and, according to the EMF study, would be about $3.8 trillion around 2040.

Insights for Policy

The cost of meeting a targeted level of emissions is related to how far the baseline carbon emissions in a future year deviate from the target, rather than how far today's emissions are from the target. Technological innovation is probably the only factor that would prevent the emissions baseline from increasing throughout the next century (and thus continually moving away from a fixed target). Because the baseline forecast will likely get farther and farther away from any target for a number of decades at least, the EMF study found that annual costs of stabilizing emissions at 1990 levels would be 0.1% to 0.5% of GDP in 2000, but that those costs would rise to 0.2% to 0.75% in 2010.

The EMF study also shows that control costs rise at an increasing rate with the stringency of the goal. To stabilize emissions at 1990 levels would cost 0.2% to 0.75% of GDP in 2010, but the cost would jump to 0.9% to 1.7% of GDP with a 20% reduction below 1990 levels.

The EMF and other studies indicate that delaying a targeted goal by a decade or so would have a small impact on cumulative emissions but would result in huge cost savings. The benefit comes from avoiding high marginal control costs today, allowing greater time for an economy to adjust to meeting a target, and permitting the introduction of innovative technology. For example, Manne and Richels estimate the cumulative (1990-2100) discounted (at a 5% real rate) cost to the United States economy of stabilizing carbon emissions at 1990 levels by 2000, then cutting 2010 emissions to 20% below 1990 levels, and maintaining that level through 2100. They estimate the cumulative discounted cost to the United States to be $1.4 trillion. Slipping the carbon constraints by 10 and 20 years would reduce cumulative discounted costs by 25% and 40%, respectively. Yet a 10-year delay would increase U.S. cumulative emissions over the 1990-2100 period by only 3% or 4%; a 20-year delay would increase cumulative emissions by 9%.

Manne and Richels also outline a path of more emissions than the target in the near term and lower than the target in the more distant future in order to achieve the same cumulative emissions over the next century. Such a path of more emissions now and less later would save 35% of the $1.4 trillion by not forcing the economy to meet fixed targets quickly.

If carbon taxes are used to reduce emissions, the economic impact is affected by how the tax revenues are used. Most models assume that carbon taxes are rebated in a lump sum fashion and that budget balances are unchanged. In its OECD study, DRI assumed that carbon taxes were rebated via the personal income tax. These assumptions are made in order to separate purely fiscal effects from the cost of adjusting to higher energy prices.

Several studies in the EMF assessment found that GDP losses can be reduced if carbon taxes are substituted for existing but highly distortive taxes (for example, taxes on investment). Model results also show that GDP losses would be increased if carbon tax revenues were used to finance government spending. With respect to the argument that carbon taxes might be a good substitute for taxes on investment, there are more direct and better ways of reforming the federal tax system than the roundabout way via greenhouse policy. For example, even greater reduction in economic distortions can be achieved if a broad-based consumption tax, rather than a carbon tax, is substituted for the taxes on investment. As David Montgomery, an economist at DRI/McGraw-Hill who formerly held senior positions at the Congressional Budget Office and U.S. Department of Energy, explains:

"The points on which economists agree — that taxes discouraging investment are costly and that some taxes on consumption could provide the same revenues in a less costly way — do not imply that carbon taxes are the best source of revenue for tax reform. Carbon taxes high enough to achieve emission reduction goals may be more costly than the taxes on investment they replace, benefits of increasing investment may be exaggerated, and other consumption taxes could raise revenues at much lower cost than carbon taxes. In addition, carbon taxes are not pure consumption taxes. They also fall on investment and, therefore, can have deadweight losses, on the margin, similar to those of taxes on income from investment."

In reality, it is unlikely that highly regressive and regionally inequitable carbon taxes would be rebated via reductions in corporate income taxes or via implementation of new investment incentives. This is especially true given the large amounts of tax revenues that would be raised. A $100/tonne carbon tax could raise around $135 billion/year. In comparison, corporate profits tax revenues totaled $100 billion in 1992.

Furthermore, the revenues from the BTU tax proposed in 1993 were not to be used to reduce taxes on investment (in fact, business income taxes, on net, were raised by the budget proposal).

Opportunity Costs of GHG Emission Constraints

After a review of the cost estimates from elaborate economic models, it is important to discuss qualitatively the cost to society of foregoing other worthwhile activities if funds are diverted to GHG controls. The human agenda is

filled with unmet needs while financial resources and political capital are scarce. Actions on GHG emissions necessarily mean less action taken on other critical needs.

In developing nations, reducing poverty is the most pressing need. As the World Bank notes, "The elimination of poverty and the achievement of economic stability and growth are main priorities for development and ... will be fundamental if environmental problems are to be successfully addressed."

There is nothing speculative or hypothetical about the immediate, life-threatening local problems that millions of people face each day in much of the world. One-third of the world's population is without adequate sanitation. Over one billion people are without safe water. Hundreds of millions of cases of debilitating parasitical diseases, cholera and typhoid are the direct result of the lack of these basic amenities today. The deaths of two million children from diarrheal diseases could be prevented each year with adequate sanitation and clean water. Only with improved economic performance can those local problems be addressed.

Economic development creates the means and the will to take action on a whole array of pressing needs. It is no accident that concern about industrial pollution or potential climate change is most acute in those countries that have already benefited from a long period of sustained economic development based on the use of fossil fuels.

Possible problems from climate change that may arise 50 years in the future are far down the list of concerns that developing countries are likely to worry about. As Thomas Schelling explains: "... we cannot expect China, India, the Soviet Union, the countries of Eastern Europe, or the rest of the developing world to burden their current economic growth for the sake of a possibly more benign climate 75 or 100 years from now than they should otherwise anticipate."

Mr. Schelling continues, "An additional point is that many of these same countries — notoriously Eastern Europe and the Soviet Union, as was publicized during 1990 — have been poisoning their drinking water, the air they breathe, and their topsoil, so much that any economic penalties they are prepared to incur to clean up emissions should, for at least a generation, concentrate on immediate threats to health and child development. Carbon dioxide will appear benign by comparison."

Instead of undertaking costly efforts to force reductions in GHG emissions today, a strong argument can be made that these countries would be better off putting their money into high-return investments in education and basic infrastructure and using the returns to deal with any climate concerns in the future via adaptation, adoption of improved technology, or other means.

On the environmental front, U.S. business and government are busily adjusting to costly changes mandated by the Clean Air Act Amendments of 1990, the Energy Policy Act of 1992, CERCLA, RCRA, the Clean Water Act, and the cleanup of DOD and DOE facilities. EPA has estimated that the costs of environmental regulations will increase to $185 billion (1990$) annually by 2000 or 3% of GDP (vs. $115 billion and 2% of GDP in 1990). These estimates do not include the costs of alternate fuel mandates under the Energy Policy Act of 1992, the likelihood that Northeastern states will adopt California vehicle standards under the recently amended Clean Air Act, or the cost of any greenhouse-related program. Based on the DRI study discussed above, a policy to limit year 2000 CO_2 emissions to 1990 levels would add about $100 billion to EPA's estimate of $185 billion in other environmental regulatory costs, meaning that year 2000 costs would more than double their 1990 level.

The domestic policy agenda is also full. Health care, education, training, and increased private and public investment are just some of our pressing needs that would compete with GHG emissions controls for funds. President Clinton's goals of improving international competitiveness and promoting high-wage jobs would be hampered by policies to force costly GHG emission controls on industry (recall DRI's projection of an accelerated shift away from the high-wage industrial sector toward the service sector under GHG emission constraints). Climate policies also would likely compete and conflict with numerous policies having to do with power generation, transportation, manufacturing and agriculture.

A decision to enforce compliance with GHG emissions targets creates a mandate like an entitlements program whose goals are to be met regardless of costs or the needs of competing uses for funds. In some sense, a GHG emissions target is even worse than a new entitlements policy because it will likely be implemented largely off-budget, via regulation which imposes costs on industry and consumers entirely outside of the Congressional budget process, and without annual oversight by Congress in which trade-offs must be made between more funds for greenhouse emissions control vs. more funds for medical care or for training and investment incentives to improve U.S. competitiveness.

On the international front, completion of the GATT Uruguay Round and NAFTA, Russian aid, regional conflicts, and economic and democratic reforms in developing nations are just some of the pressing problems requiring coordinated action. On the environmental front, treaties dealing with biodiversity, forest initiatives and CFC usage must either be completed or implemented fully. The reality is that greater attention on speculative global climate issues will divert international attention from these more certain and immediate needs.

Policy Analysis

Designing an appropriate regulatory response to potential global climate change is complicated by five factors: (1) the unusual degree of scientific uncertainty; (2) the uncertainty concerning the ecological, economic and social consequences of potential climate change; (3) the uncertainty concerning the costs and benefits of constraining emissions; (4) the global nature of GHG emissions and potential climate change; and (5) the very long time scales involved. The first three factors have been discussed above; the last two deserve special mention.

International Dimension

Because of global economic integration, emission constraints in one nation or a subset of countries can actually lead to increased emissions in the rest of the world. If a carbon tax levied unilaterally by industrialized nations were to drive down oil demand, for example, world oil prices would fall. Lower oil prices would spur oil consumption and, hence, increase carbon emissions in other nations. Not only would the non-controlling nations' general energy intensity increase, but they would also gain production of energy-intensive manufactured goods that would be shifted out of industrialized nations. The point is that a country is deluding itself if it measures only the impact of emission controls in its own country and ignores the rebound effect on emissions in non-controlling nations.

Concerns about international competitiveness and the small impact of unilateral action on global emissions limits the feasibility and likelihood of significant unilateral action. The path to a coordinated worldwide response, however, will be littered with difficulties. The international community would have to wrestle with issues such as: how far should each country go in restraining emission controls; what share of the cost should be borne by industrialized nations vs. developing nations; and how should efforts to restrain deforestation be compared with reductions in fossil fuel and agricultural methane emissions. Many a country will be more than willing to vote for imposing a disproportionate share of costs and reduced international competitiveness onto other nations.

Worldwide consensus would also be complicated by the likelihood that the impact of any climate change could vary widely and could be positive for some countries. For example, the former Soviet Union and Canada may find that a somewhat warmer temperature would be an economic benefit in their frozen northern provinces.

A "free riding" country that fails to reduce emissions and therefore avoids costly emission controls would still "benefit" if other nations acted to reduce emissions. Voluntary compliance with a global plan would likely fail, and some

type of punishment would have to be imposed on scofflaws — not an easy proposition in the absence of a world governing body with substantial police power.

Very Long Time Scales

What matters for climate change is cumulative emissions over a long period of time — not emissions today or in 2000. Thus, the critical dimension for policy making is not the next seven years but the first 50 to 75 years of the next century. It is not necessary to make a policy decision today that will be in force for 100 years. Policies can be changed as new information about science, economics and technologies becomes available. Costs can be lowered by delaying action until the time when research has advanced the cost-competitiveness of less carbon-intensive technologies and may be largely avoided altogether if action is delayed and science finds climate change to be minimal and benign. On the other hand, climate changes could not be immediately reversed; reversal, if possible at all, could take many decades.

If near-term GHG emission restraints are deemed necessary, it is critical to realize that capital turnover takes time, as do bringing on new supplies and invention and dissemination of new technologies. These processes can be accelerated but at a cost. It may be more costly to achieve a less restrictive target quickly than to achieve a more restrictive target over a longer period of time.

Because the costs of taking action now will precede any benefits by a matter of decades, the proper discount rate is a critical part of cost-benefit analysis. Some argue that the use of discounting is generationally inequitable, because it downplays potential climate costs borne by future generations, who have no voice in emission decisions made today. On the other hand, neither can future generations, who are likely to be considerably wealthier, vote today to dissuade implementation of costly emission reductions that would slow improvements in standards of living and health for their ancestors, especially those desperately poor ancestors in developing countries.

The inescapable economic fact is a scarcity of resources relative to needs. The use of a discount rate allocates scarce resources to more valued investments. It is wiser to invest in high-return endeavors today in order to provide future generations with more funds to address future problems if they arise.

Criteria for Policy Analyses

A wide range of response options is under consideration to reduce the alleged threat. In deciding how to choose among proposed policy options, society needs to develop more effective and useful instruments, institutions, and methods to evaluate response options and the costs vs. possible benefits. To that

end, the following criteria should be among those applied to evaluate response options:

- Policies should consider all sources and sinks (natural and anthropogenic) that influence the greenhouse effect.

- Policy analysis should include evaluation of related energy, economic, social, and environmental issues.

- Policies should be selected based on their economic and environmental benefits and costs.

- Policy analysis should recognize and consider the extent of current uncertainty in scientific knowledge and in predicting the economic, social, technical, and energy implications of different policies.

- Policies should be sufficiently flexible to be changed as scientific understanding improves, as technology develops, and as we gain experience with the policies themselves.

- A level playing field should be adopted with respect to different sectors and countries.

Policy Options

The policy options to address potential global climate change can be divided into five broad categories: (a) scientific research and data collection, to better understand factors which affect climate and the impact of climate change on ecological systems, economies and societies; (b) mitigation, to reduce emissions of GHGs, including technological means to sequester CO_2 captured during the production and use of fossil fuels; (c) technology cooperation, to promote the diffusion of more efficient, less polluting technologies, especially from developed to developing countries; (d) adaptation, to adjust to climate change through such actions as developing drought-resistant crops or building dikes to protect against rising sea levels; and (e) intentional climate modification (geoengineering), to create technological means to alter climate in order to offset potential enhancement of the greenhouse effect or its impacts.

Scientific Research

A major improvement in scientific understanding is required before proceeding with efforts to reduce GHG emissions (beyond those that clearly make economic sense in their own right). Otherwise, it will not be possible to answer the critical questions of how much reduction (if any) of which GHGs is necessary within what time period to prevent or mitigate against what types of economic and ecological impacts. The highest priority should be in the areas of

establishing long-term monitoring of climate change, better understanding of climate processes, climate modeling, and improved understanding of the consequences of climate change for society and ecosystems.

In the quality and extent of its research on climate change, the United States has provided global leadership. The U.S. government has established an interdisciplinary global change research program. This program is aimed at: (1) gathering data to document global climate change; (2) increasing understanding of key global climate processes; (3) improving the ability to forecast global and regional climate and environmental changes, and; (4) providing an ongoing assessment of scientific knowledge and implications for policy.

The U. S. government has spent over $5 billion on global climate research since 1990 and an additional $1.8 billion has been proposed for fiscal year 1995. The United States provides more than half of the worldwide spending on global climate research.

The scientific community has proposed a number of international, long-term studies aimed at fundamental issues related to climate change. These include the International Geosphere Biosphere Program, the Global Climate Observing System, and the World Climate Research Program, among others. These programs will require many years to implement and conduct and they require funding principally from national agencies. The United States has been a major supporter of these international scientific programs and should encourage other countries to contribute to and participate in these research efforts.

Mitigation Near-Term Policies

Because of scientific uncertainty and competing societal needs for scarce resources, the U.S. government should continue to pursue an economically-justified mitigation strategy as the best short-run strategy to address the potential problems of climate change. Such a strategy would slow the growth of GHG emissions and at the same time yield non-greenhouse benefits commensurate with its costs. These policies involve low-risk, relatively low-cost options; such a strategy does not imply that we should do nothing and spend nothing.

Sustained research and development programs for low-carbon or carbon-free energy, for energy efficiency, and for technology to remove and sequester CO_2 emissions would be a major element of a near-term mitigation policy. A research and development (R&D) program sustained over a period of decades is needed because major breakthroughs in energy technologies (photovoltaics, for example) do not appear likely for many years to come. It is important to base such a research program on sound science rather than political considerations.

A number of cost-effective energy efficiency steps can be taken. Demand side management programs by electric utilities, if properly designed, can lead to cost-effective efficiency improvements. Accelerated scrappage of old vehicles can provide a relatively low-cost way of reducing urban ozone pollution, while providing the added benefit of substituting more energy efficient new cars for older, less efficient ones.

Initiatives to improve energy efficiency have been cost-effective when driven by market forces, technology, or investment opportunities. Improvements are derived from individual companies drawing on their experience and knowledge of specific circumstances and those of their business sector. This approach is flexible and productive and avoids inappropriate regulations.

Several actions can be taken to facilitate the cost-effective substitution of low-carbon fuels for high-carbon ones. Implementing reforms in the Energy Policy Act of 1992 can provide greater opportunity for independent power providers, most of which will be gas-fired. Streamlining nuclear licensing could provide opportunity for this non-carbon based technology to compete with fossil fuels for electric power generation, although concerns about nuclear safety, waste disposal and proliferation still need to be addressed.

Policies should take into account costly mandates under other legislation that will also affect GHG emissions. Under the Clean Air Act Amendments of 1990, motor vehicles and electric utilities are required to cut emissions of nitrogen oxides, also a GHG. The Clean Air Act limitations on sulfur dioxide emissions from coal-based electric power plants are likely to increase electric utilities' use of natural gas, a lower-carbon based fuel. Industry should be given time to adjust to these costly regulations before any new mandates are issued to force even more costly cuts in GHG emissions.

The U.S. government has proposed plans to plant 1 billion trees per year over the next decade. Achievement of this goal would ensure a continuation of the reforestation trend in the United States that has pushed today's total volume of forests 25% higher than in 1952.

General policies to encourage investment and R&D will improve U.S. economic performance and provide environmental benefits by encouraging earlier retirement of less efficient technology. R&D tax credits and investment and savings incentives can have positive environmental side effects.

International Near-Term Policies

Much of the international debate focuses on centralized and bureaucratically driven initiatives aimed directly at GHG emissions, especially the need to improve energy efficiency in these countries. However, much could be accom-

plished worldwide if near-term efforts were focused on decentralized initiatives aimed not at environmental issues per se but that have considerable environmental side benefits.

The industrialized world, through its own lending and aid practices, should encourage former communist countries and developing nations to accelerate economic reforms. Only through market prices and competition at home and via trade will the forces for energy efficiency, fuel substitution, technological progress, and structural change move to the forefront.

The World Bank estimates that energy subsidies cost Eastern Europe, the nations of the former Soviet Union, and developing nations $230 billion per year. These energy subsidies are more than four times the size of official development assistance from the industrialized world. More than half of the air pollution in Eastern Europe is attributable to energy subsidies. On average, electric prices today cover less than half of supply costs in developing countries. According to the World Bank, a move to market pricing worldwide, including elimination of coal subsidies in Europe and other industrial countries: "... would not only produce large gains in efficiency and fiscal balances but would sharply reduce local pollution and cut worldwide carbon emissions from energy by 10%."

Especially flagrant environmental abuses and inefficiencies have been evident in state-run enterprises. There has been a strong state role in energy-intensive, sectors — power generation, cement, steel, mining, oil and gas production and refining. Exposing these state enterprises to competition, particularly by opening up the power generation sector to private investment, would have a major impact on energy efficiency and would provide important local and global environmental benefits.

Trade liberalization will provide developing nations with the foreign exchange necessary for an increased flow of more energy-efficient, less polluting equipment and consumer products. The World Bank estimates that a successful conclusion to the Uruguay Round would generate export earnings of $65 billion a year for developing countries by 2000. Increased foreign competition in domestic markets will also force formerly protected industries to become more efficient. Opening up agricultural markets in Europe and Japan will allow substitution of products from less energy-intensive farms in the developing world and elsewhere.

An international goal should be to protect carbon sinks, especially the species rich forests in developing nations. Developing nations should be encouraged to eliminate logging subsidies. In a study of five African nations, the World Bank found that logging fees covered from 1% to 33% of the costs of reforestation. Agricultural programs that improve farm yields warrant support so that less forest and undisturbed land is required to feed growing populations. Forest

preservation has an immediate payoff in terms of protection of species. Costly action to reduce GHG emissions from industrialized nations does nothing to protect habitat today and provides, at best, a speculative benefit to species decades in the future.

Direct international aid can also play a role. An example is the Global Environmental Facility (GEF), administered by the World Bank, which is intended to finance pilot projects in developing nations aimed at reducing deforestation and improving energy efficiency.

Future Mitigation Steps

What steps should be taken in the future if research provides solid evidence of significant and costly climate change? One should not underestimate the magnitude of government intervention in the economy that some are likely to advocate to achieve drastic GHG emission reductions. Carbon taxes that triple prices for energy consumers and that would raise several hundred billion dollars could be necessary to meet severe emission limits. Technology standards and mandates that affect basic economic decisions in manufacturing, power generation, transportation and virtually every sector of the economy might be the way that governments would actually implement emission limits. One could imagine nationwide allocation controls reminiscent of the 1970s to dictate where scarce fuel — a scarcity established by regulatory mandate — would be ordered to be distributed as regions and sectors vie for special considerations. Past government attempts to influence which fuels to use, for example, the federal law prohibiting the use of natural gas in new industrial and electrical utility boilers in the early 1980s, do not inspire confidence in the U.S. government's ability to enact wise fuel use mandates.

Despite some theoretical advantages, many practical issues make reliance on large carbon taxes both problematic and unlikely. Under recent energy tax proposals, regional, sectoral and political considerations led to numerous discriminatory exemptions and distortions. The impact on internationally traded goods from an energy tax is especially complicated to overcome. If taxes are unilaterally imposed on U.S. goods, U.S. manufacturers will lose markets at home to imports and abroad to goods in which embedded energy is not taxed. Not only would the United States export jobs and income because of a carbon tax, it would export carbon emissions — as fuel previously burned in America to make products is now burned overseas. Use of tariffs on imports and tax rebates on exports to protect domestic firms would be complicated to administer and could lead to escalating trade wars.

Concerns about the regressivity of a carbon tax also limit its political viability. James Poterba, economics professor at MIT, has estimated that a $100/ton carbon tax would consume 10% of the income of families in the bottom 10% of the income distribution vs. 1.5% in the top 10%.

The economic cost of limiting emissions to 1990 levels would reach $100 billion in 2000 according to DRI, and the cost would rise significantly if emissions cuts below 1990 levels were mandated. Given the drawbacks of energy taxes, it is unrealistic to expect the passage of a carbon tax large enough to make the cuts in emissions that some will advocate.

The predominant method of environmental regulation in the United States has been to set emissions or efficiency standards and/or to mandate use of specific fuels or technologies. The drawbacks to command and control regulation are well- known. Governments cannot possibly directly control emissions from so many different sources; nor can regulators develop enough information to determine cost-effective steps; nor have politicians permitted a high priority to be placed on cost-efficiency during the regulatory process.

Regulation often protects existing, less efficient, more polluting capacity by enforcing much more stringent standards on new cleaner plants or equipment. For example, by raising the cost of new automobiles, corporate average fuel economy (CAFE) standards have the perverse effect of delaying the scrapping of less fuel efficient and more polluting automobiles. Moreover, a standard that specifies a control technology often acts as a barrier to innovations because of the lengthy review process before these innovations can be approved for use.

Regardless of the method of control chosen, unilateral U.S. efforts would not be enough. An international agreement requiring large global reductions in CO_2 emissions could very well require a radical transformation of national and international governance. To be effective, implementation and administration of international agreements could require the ceding of considerable power to international governing bodies — affecting national security, overriding national economic policymaking, and conflicting with constitutional obligations of national legislative, executive and judicial bodies. One should not be sanguine about the prospect of vast international and national bureaucracies implementing all-encompassing energy and technology policies and empowered with significant power to police and enforce compliance.

Consider, for instance, the issue of how to assign the emission rights across nations in order to meet an international target (a substantial international literature has been developed on this very issue). Critical factors would include the process by which total allowances by nation are set and allocated (effectively limiting national energy use through decisions of some international commission), the compliance monitoring process, and the means for enforcement of agreements. Trading of emission rights across nations might allow nations to exceed an arbitrary emissions limit but could entail enormous outflows of funds from nations needing to purchase more permits. International redistribution of wealth could be significant. Thus, not only would a country, such as the United States, have to incur high costs from reduced emissions and international competitiveness, it might also have to ship billions of dollars overseas to purchase permits.

The ultimate policy decisions should be driven by a rational assessment of costs and benefits. Even if future scientific research establishes the magnitude and timing of future climate change as a result of anthropogenic GHG emissions, a determination that climate will change in the future should not be used to stampede governments into trying to effect a wrenching transformation of society without regard to cost and social impacts. The near-term costs of emission reductions would still need to be weighed against the future costs and benefits of future climate change.

It may well be that adaptation to some future climate change would have a smaller impact on economies and societies than would the vast expansion of government powers that some would advocate for an immediate and drastic reduction in fossil fuel use. Mitigation, adaptation, carbon sequestration and geoengineering efforts should all be considered if science later establishes that significant climate changes will occur. The relative costs and benefits of the various options should guide policymakers on the specific combination and timing of these policy options.

Carbon Sequestration as a Future Mitigation Option

In considering long-term options for large-scale energy systems that emit less CO_2, discussions often center on novel, currently noncommercial sources, such as solar voltaics and renewable biomass crops, or even more futuristic options such as fusion or solar power satellites. However, it is important to recognize that options also exist that might allow continued use of fossil fuels but with significantly lower emissions of CO_2. These options include techniques to separate and store CO_2 emissions from large combustion facilities (power plants or refineries, for example), or to convert them to other products. Potential storage sites include depleted oil and gas reservoirs, salt domes, deep aquifers, and the deep ocean. While carbon sequestration technologies are expensive and not commercially available today, they may turn out to be less expensive and more environmentally benign than exotic and unproven fuel alternatives.

Reforestation as a Future Mitigation Option

Reforestation presents a way to sequester large amounts of carbon. The IPCC estimates that the global biomass currently stores some 550 ± 200 GtC and that another 1500 ± 200 GtC are stored as organic matter in soils. Annual fossil fuel emissions of 6 GtC could thus be offset if we could engineer an annual increase of 0.3% in the amount of carbon stored in the biosphere and soils.

The most attractive choice appears to be carbon uptake and storage in trees. We know how to grow trees and we know that woody biomass stores a large quantity of carbon with minimal amounts of other nutrient elements. If global land use could be altered to return to the forest cover that existed in 1800,

then some 100 GtC could be removed from the atmosphere, an amount equivalent to 15 years of emissions from fossil fuels at today's rate of use. Numerous studies, such as the 1991 NAS report, show that reforestation is among the most cost-effective options.

Of course, forests cannot continue to remove CO_2 indefinitely. The rate of uptake will decline over a period of several decades as the forest matures. However, growing forests could slow the rate of growth of atmospheric CO_2 and provide time to assess actual climate change and its impacts, to develop alternate energy systems, and to allow human systems to adapt. Protecting and expanding forests also promote other social objectives: protecting biodiversity, improving watershed quality, and providing forestry products and recreational opportunities. It must be recognized, though, that global forestry programs involve serious international political issues associated with national sovereignty and contentious local political issues concerning access and use of land.

Technology Cooperation

Money and effort spent in the United States to reduce the threat of climate change might achieve greater results if applied in developing countries. These countries have pressing internal needs to use more efficient, less polluting technologies. Thus, efforts to promote cooperative deployment of appropriate technology appear to offer a win-win opportunity in the global effort to address climate change.

Through its multinational companies, the U.S. energy industry has a long and successful record of technology cooperation with developing countries when appropriate conditions exist. Key criteria for promoting technological cooperation include marketplace opportunities, acceptance by the host countries of multinational firms, and opportunities to realize an adequate return on investment.

When these criteria have been met, U.S. energy companies have successfully entered into partnerships and shared development of infrastructure and operations and mutual commercial reward. In these cases dissemination of the best technology is of mutual interest and becomes an essential element of normal business practices. These circumstances offer the host country the best chance of actually assimilating technology and developing the internal capability to pursue future opportunities.

In the negotiations for the framework convention on climate change (discussed in Appendix I), developing countries (the so-called G-77 nations) called for preferential, non-commercial transfer of technologies. Such terms offer little or no incentive for effort by private sector companies and little scope for assistance by governments which do not own property rights to most useful technologies. The United States can encourage technology cooperation between private companies and developing or former communist countries by encour-

aging those countries to establish conditions that allow for mutually acceptable investment by multinational corporations.

The framework convention stipulates that new and additional aid will be provided by developed to developing nations, including funds to promote technology transfer as a response to climate change. In this case the Global Environmental Facility acts as the institution for financial arrangements. The United States must seek to insure that arrangements under the convention and the GEF support rather than interfere with commercial opportunities for multinational corporations.

Adaptation

Because developing countries will strive to improve their impoverished standards of living, their use of fossil fuels will continue to increase for decades to come. As a consequence, global GHG emissions will continue to increase regardless of actions taken in developed countries. Should climate change as a result, adaptation will have to be a basic feature of any response strategy.

Adaptation to climate change can take two forms: (1) adaptation by people and businesses to market signals that reflect the impacts of actual and expected climate change and (2) efforts by governments to anticipate climate change and to build that anticipation into infrastructure, budget plans, and regulatory and tax decisions. Mitigation and anticipatory adaptive actions would require costly action to be taken far in advance of potential climate change, while many adaptive actions would be delayed until market forces react to actual climate change.

Society already has shown it can adapt and prosper in differing climates and that it can protect itself from naturally occurring climate variability. Many of the potential consequences of future climate change, such as droughts and floods, already occur from time to time in many regions due to existing natural climate variability. Steps taken to provide greater protection against existing threats also provide protection against possible consequences of future climate change. For instance, R&D and commercial technologies exist to provide agricultural crops and cultivation techniques that are more adaptable to climate changes in growing seasons or water availability, and to protect against floods, sea level rise, and coastal erosion. Extending their utilization might provide additional protection against existing climate variability and improve the ability to adapt to any future climate change. In that sense, these may be considered additional near-term options.

Society has in place institutions charged with long-term planning, such as those that manage infrastructure, watersheds, coastal protection, and public lands. Additional scientific research on potential regional climate changes and the adaptive capability of ecosystems and economies is needed before these agencies take any significant anticipatory actions. Planning related to public and

private investment in long-lived systems (such as bridges, roads, power plants, and flood control systems) should consider marginal additional investments that might operate better in the event of future climate change. Society can also promote research in areas such as genetic engineering that might offer more powerful adaptation options in the future.

Joint Implementation

To be effective, any climate change program must recognize that the issue is global in nature and that most of the future growth in man-made emissions will come from developing countries. As a result, the Framework Convention on Climate Change acknowledges that nations may implement policies to address potential climate change jointly with other nations. The United States has proposed a pilot program to assess and design procedures for Joint Implementation nationally and internationally. While the details of the pilot program have not been developed, it makes sense to recognize actions that might be taken by U.S. entities to reduce GHG emissions in other countries, thereby providing a critical and cost-effective mechanism to encourage the introduction of cleaner, more modern technology where it is most needed. If designed appropriately, it should be a "win-win" policy for the United States to promote technology cooperation and expertise to help the developing nations increase their economic growth while slowing the growth of their GHG emissions. However, care must be taken to avoid a costly new bureaucracy both within the U.S. government and the United Nations to administer any such program or regulations that limit the role of the private sector.

Climate Engineering

The National Academy of Sciences study indicates that technically feasible options do exist that may counter some or all of the anticipated climate change from an enhanced greenhouse effect, or that may alter the geochemical cycles that influence the GHG concentrations, especially CO_2. Among others, these options include the possibility of promoting cooling by deploying materials that reflect sunlight, or by enhancing natural processes that remove CO_2 from the atmosphere by fertilizing the marine biosphere. The report clearly notes that such steps should not be taken today because understanding is too limited to preclude the possibility of unintended side effects. The National Academy of Sciences study recommends that society invest in research to better understand the potential of geoengineering as a strategic insurance option to protect against climate change.

Conclusions and Recommendations

The future consequences of continued increases in the concentrations of atmospheric GHGs are shrouded everywhere in significant uncertainty. Many proposed response actions are very risky and have enormous and immediate social, political and economic costs. Commercially feasible technologies simply do not exist today that could eliminate the potential for climate change; and there is no guarantee concerning the time, cost or ultimate success of efforts to shift to significantly less carbon-intensive fuels and technologies. It is clear that the underlying uncertainty in scientific, technical and social aspects of the issue will require decades to resolve and that policymakers will have opportunities to take action and make adjustments as knowledge and technology progress.

The claim that serious impacts from climate change have occurred or will occur in the future simply has not been proven. Observations have not confirmed changes in climate from increases in GHGs and descriptions of future changes rest on results from unvalidated and seriously incomplete models. Claims of an impending catastrophe rest on little more than speculation. Consequently, there is no basis for the design of effective policy actions that would eliminate the potential for climate change. Certainly, proposals to stabilize emissions in the United States and other OECD nations fall far short of the mark as emissions growth will occur predominantly in developing nations. But global emissions would need to be reduced by more than 60% to stabilize atmospheric concentrations. Concerns about uncertain climate change would be better addressed by sustained programs of climate research and R&D into alternative energy, carbon sequestration technology and geoengineering than by programs with large near-term economic costs.

The cost of inaction is very speculative and remote in time. But the cost of significant near-term restrictions on greenhouse emissions would be real and immediate; we run the risk of implementing inappropriate policies that later turn out to have been misguided. DRI estimates that the cost of stabilizing emissions at 1990 levels by 2000 would be $100 billion/year in the United States alone. EMF studies estimate that a phased-in plan to stabilize worldwide emissions at 1990 levels could end up costing close to $4 trillion/year (1990$) by around 2040. Even these estimates are likely to be understated because they are based on the assumption that carbon constraints would be imposed in a least-cost manner, which is clearly not consistent with U.S. regulatory experience. Developing countries simply have much more pressing and immediate needs associated with alleviating poverty and can ill afford to retard their economies in order to address speculative climate changes that might occur decades in the future.

While it may be that the need for more stringent actions to control GHG emissions will be established scientifically in the future, it is hardly clear that a delay will make the effort more difficult. If we pursue policies today that encourage cost-effective efficiency improvements and technological innovation and promote free market economies worldwide, then future efforts with clearer goals would be easier to achieve and at lower cost. Waiting for scientific knowledge to advance could very well avoid the need to move toward the centrally planned government intervention, at both the national and international levels, that many are advocating.

Because of the uncertainty about the science and the high costs of action, emission targets, timetables, carbon taxes and other costly regulations are not now justified. Instead, society should promote the development of scientific knowledge and advanced technologies. Society can also undertake a set of low-cost options which are justifiable on their own merits regardless of climate issues and are directionally constructive with respect to climate concerns. When combined with serious attempts to improve our understanding of the issue and reduce the uncertainty surrounding it, these options provide a viable approach for today.

The Global Climate Coalition recommends a policy including the following options:

• Accelerate the pace of research into basic climate science and impact assessment.

• Identify and pursue measures that will reduce the threat of climate change, yet also make sense in their own right.

• Establish sustained research and development programs that improve the ability to economically produce and utilize energy with less potential for the accumulation of greenhouse gases.

• Expand efforts to understand and communicate the economic, social, and political consequences of both climate change and proposed policy responses.

The following specific actions should be considered:

• Emphasize scientific research that focuses on: acquisition of appropriate data to demonstrate whether or not climate is changing; monitoring potential impacts on ecosystems; studies that improve fundamental understanding of critical climate processes, especially clouds, oceanic circulation, the role of the biosphere, and the carbon cycle; and developing improved capability in modeling climate and its influence on ecosystems.

• Provide sustained research funding for the potential long-term options of carbon sequestration and geoengineering.

• Take steps to provide greater protection against existing climate-related threats (for example, develop drought resistant crops) as a way of providing protection against possible future climate changes.

• Implement energy conservation programs that are justified in their own right.

• Protect carbon sinks by slowing deforestation, especially in the tropics, and by encouraging reforestation.

• Nurture international cooperation on global environmental issues.

• Emphasize international initiatives to liberalize trade, open markets, reduce state intervention, especially in the power generation and petroleum sectors, and eliminate energy subsidies as the best way to encourage improved efficiency worldwide.

• Promote technology transfer to developing nations by supporting policies that encourage investment by multinational companies.

The GCC recommends adopting the following criteria for judging policy initiatives whose purpose is to reduce greenhouse gas emissions:

• Cost-effectiveness.

• No harm to U.S. international competitiveness, investment or employment.

• No new taxes.

• Nondiscriminatory treatment of all industries and regions.

• Flexibility (i.e., can be adjusted as science evolves).

• Simplicity of administration.

Appendix I: United Nations Activities

The United Nations established an Intergovernmental Panel on Climate Change (IPCC) to prepare scientific and technical assessments and an Intergovernmental Negotiating Committee (INC) to develop a Framework Convention on Climate Change. Once the convention enters into force, the INC will be superseded by a Conference of Parties (CoP). In the interim, the INC continues to function, developing preparatory work for the CoP. The Framework Convention entered into force on March 21, 1994, 90 days after a total of 50 nations ratified its terms. National Action Plans are to be submitted by these nations by September 21, 1994. The first meeting of the CoP is expected in early 1995. The United States ratified the convention in 1992.

IPCC produced a major 1990 assessment covering science, impacts and response options, and an update in 1992. IPCC has now begun a second assessment, to be completed in 1995, covering: (1) science, (2) impacts and response options, and (3) crosscutting economic issues. Unlike previous assessments, IPCC proposes to include comprehensive economic assessment of impacts, adaptation, and mitigation.

By its charter IPCC does not conduct original research. Rather, it assesses available published results; in a few instances, it develops new results. For its 1990 and 1992 reports, IPCC prepared rather controversial scenarios of future emissions of GHGs. Its current work includes developing methods for reports required by the Framework Convention. For example, IPCC previously developed a methodology for assessing national impacts of climate change and now, with the International Energy Agency (IEA), is developing methods for national emissions inventories. INC has also requested that IPCC undertake a review of the adequacy of existing emission scenarios.

Negotiations of the Framework Convention centered on two issues: first, targets and timetables for stabilization of greenhouse gas emissions by developed countries (typically with stabilization at 1990 levels by 2000) and, second, provision of additional financial aid and preferential, noncommercial technology transfer to developing countries. The actual convention obligates developed countries to adopt programs to limit emissions and to provide new and additional financial aid from developed to developing countries. However, following United States rather than European Community (EC) positions, the convention does not impose targets and timetables; and, following developed country positions, it does not specify amounts or terms of financial aid.

The Framework Convention contains two provisions that will drive future discussion. First, it imposes a rigorous national reporting obligation covering sources and sinks of GHGs, programs to limit emissions, and projections of future emissions. Second, it states as its ultimate objective "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." The analysis of national reports under the Framework Convention and efforts to define and develop a response to the objective will be central to future discussion. (Recall that estimates suggest that stabilization of atmospheric CO_2 concentrations at today's level would require CO_2 emissions reductions of more than 60%.)

Appendix II: U.S. Policies

The U.N. Famework Convention and the U.S. Energy Policy Act of 1992 (EPAct) are driving U.S. climate policy. On October 15, 1992, the U.S. Senate ratified the Framework Convention, which calls for each developed country participant to develop a national plan to mitigate GHGs. As part of the Energy Policy Act of 1992, the Secretary of Energy must report to Congress on the economic, energy, social, environmental and competitive implications of either stabilizing GHG emissions by 2005 or reducing CO_2 emissions by 20% from 1988 levels by 2005. EPAct also requires, by the spring of 1994, an assessment of alternative policy instruments for reducing emissions. An international environmental technology transfer program is also authorized to provide up to $100 million per year for 1993-98.

In his Earth Day 1993 speech, President Clinton reversed the position of the Bush Administration by announcing his support for a specific emission reduction target. The Clinton Administration followed up with the announcement of its Climate Change Action Plan in October 1993. This plan, which is based on voluntary initiatives and business/government partnerships, seeks to reduce GHG emissions in 2000 to 1990 levels.

According to the plan, the Administration has estimated that this will require a reduction of around 108 million tonnes of carbon equivalent by 2000, over and above what will be achieved under the Clean Air Act Amendments of 1990, the Energy Policy Act of 1992 and other existing regulations. (For example, DOE estimates that the Energy Policy Act would reduce emissions by 40 million tonnes.) Excluding the BTU tax, the 1993 Clinton economic plan (weatherization assistance, federal building efficiency improvements, etc.) is expected to reduce emissions by 5 to 25 million tonnes of carbon.

Appendix III: Other National and Regional Proposals

At national levels, a wide variety of programs and proposals is underway to address climate change. Japan announced that it would return per capita emissions to 1990 levels by 2000, although no definitive plans have been released. Japan has also initiated a significant, long-term program of research and development aimed at producing a variety of technologies that might respond to global change (and other environmental threats) and which might create new opportunities for future exports.

The EC has proposed to return its emissions to 1990 levels by 2000 and has developed a carbon tax proposal as a means to achieve the goal. The tax was to increase progressively from $3 to $10 between 1993 and 2000 on a barrel of oil equivalent CO_2 emissions. The tax proposal has evolved to incorporate significant exemptions for energy-intensive industries whose competitiveness would suffer and to include the caveat that its implementation would be contingent on major trading partners adopting programs with equivalent economic impact. The proposal triggered an EC North-South split and to date has not been approved. Nonetheless, particular countries have committed to aggressive goals on CO_2 reductions. For example, Germany aims to reduce its emissions 25-30% below 1987 levels by 2005. It remains to be seen which GHG policies will be implemented and whether these commitments will be achieved.

Developing countries insist that they should be exempt from any restrictions until they achieve appropriate development goals. However, developing countries do not share a single point of view on all aspects of climate change. There are major differences separating them, depending on the degree to which they export oil, depend on coal, contribute to deforestation, or feel at risk from climate change. They are in agreement on one thing: they agree that developed countries are obligated to provide significant financial assistance to help them develop their economies using advanced, less polluting technologies.

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Key To Acronyms

BTU	British thermal units
CAAA	Clean Air Act Amendments of 1990
CAFE	Corporate Average Fuel Economy
CERCLA	Comprehensive Environmental Response Compensation and Liability Act
CFC	Chlorofluorocarbon
CH_4	Methane
CO_2	Carbon dioxide
CoP	Conference of Parties
DOE	Department of Energy
DOD	Department of Defense
DRI	DRI/McGraw-Hill
EC	European Community
EMF	Energy Modeling Forum (of Stanford University)
EPA	Environmental Protection Agency
EPACT	Energy Policy Act of 1992
EPRI	Electric Power Research Institute
FCCC	Framework Convention on Climate Change
G-7	Group of 7 (of the world's top economic powers)
G-77	Group of 77 (of the world's developing countries)
GATT	General Agreement on Tariffs and Trade
GCM	General circulation model
GDP	Gross domestic product
GEF	Global Environmental Facility
GHG	Greenhouse gas
GNP	Gross national product
GT	Gigatonnes (1 billion tons)
GtC	Gigatonnes of carbon
IEA	International Energy Agency
INC	Intergovernmental Negotiating Committee
IPCC	Intergovernmental Panel on Climate Change
IPIECA	International Petroleum Industry Environmental Conservation Association
IR	Infrared Radiation
LNG	Liquefied natural gas
MIT	Massachusetts Institute of Technology
NAFTA	North American Free Trade Agreement
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
N_20	Nitrous oxide
NOAA	National Oceanic and Atmospheric Administration
O_3	Ozone
OECD	Organization for Economic Co-operation and Development
ppmv	Parts per million by volume
RCRA	Resource Conservation and Recovery Act
SO_2	Sulfur dioxide
W/m^2	Watts per square meter

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